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**Development of a Polar-Scanning Radiometer for  
Airborne Polarimetric Ocean Surface  
and Atmospheric Emission Studies**

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Covering the period from

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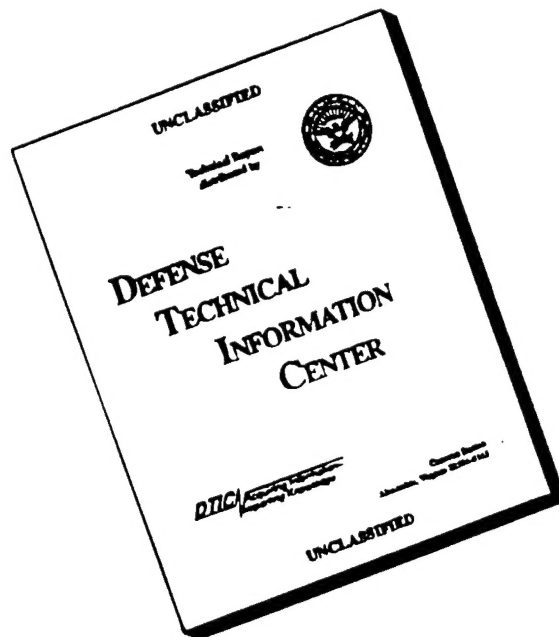
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## INTRODUCTION

The goal of this project has been to develop an aircraft instrument capable of simulating satellite observations for the purpose of developing polarimetric passive microwave wind direction sensing techniques. Remote measurements of ocean surface wind fields from space are of critical importance to weather forecasting, climate studies, oceanography and atmospheric science, and strategic defense operations. Polarimetric radiometry offers a potential lower-cost alternative to radar scatterometry for observing global ocean surface wind direction from satellites. Alternately, polarimetric radiometers should be useful in conjunction with scatterometers to improve the accuracy of wind fields measured from space. Polarimetric radiometry might also provide a means of detecting cell-top ice in convective storms by virtue of the polarizing properties of oriented ice particles, thus facilitating estimation of stormcell phase.

The project primarily involves the construction of airborne hardware for demonstrating wind vector retrieval methods and focusses on the development of a four-band fully-polarimetric imaging radiometer, the Polarimetric Scanning Radiometer (PSR). The PSR is being designed for use on a variety of aircraft, principally the NASA DC-8 and P-3B. The PSR will significantly enhance the imaging capability of the existing suite of NASA, NOAA, and NRL passive microwave aircraft instruments by virtue of its broad spectral coverage, polarimetric capabilities, and versatile scanning system. In addition, the PSR will provide the first demonstration of advanced digital correlation technology with potential applications on spaceborne sensors such as SSMT/S and converged DoD/NOAA/NASA sensors.

During the period from March 1, 1995 to May 30, 1996 the PSR was designed, all mechanical components and most electrical components were fabricated or procured, and the instrument was ~90% assembled.<sup>1</sup> In May 1996, the PSR was integrated onto the NASA DC-8 aircraft at NASA/ARC. The first data flights of the PSR are planned in conjunction with the Labrador Sea

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<sup>1</sup> Updates regarding PSR development and deployment can be found on the PSR World Wide Web home page at <http://www.prism.gatech.edu/~gt2930b/psr/>.

Experiment in January 1997. The primary goal of ocean surface measurements using the PSR will be to develop optimal strategies for the retrieval of oceanic wind vector fields from satellites.

The development of the PSR has been supported both by this grant ( N00014-95-1-0426) and a grant from NASA Headquarters (NAGW 4191). Specific tasks funded under NASA support are related to the development of the PSR digital correlator hardware, the integration of an 89.0-GHz radiometer into the PSR, and the initial modeling and analysis of polarimetric microwave imagery over the ocean. The purpose of the 89.0-GHz radiometer is primarily for stormcell mapping and further verification of the surface emission model function at a frequency high enough to preclude resonant thermal emission.

## SUMMARY OF ACTIVITIES

An intensive design and fabrication effort was undertaken starting in March 1995 with the initial goal of flying the PSR on the NASA DC-8 aircraft during the MACAWS campaign in late August, 1995. Unique attributes of PSR design effort included (1) a nearly complete reliance on computer aided design and manufacturing using a three-dimensional Autocad™ software model and computer controlled numerical cutting (CNC) techniques, and (2) the formation of an interagency design team with the requisite experience. Participants in the design and fabrication effort at Georgia Tech (in addition to the authors) included J.D. Brown, C. Campbell, D.B. Kunkee, E.A. Panning, and E. Thayer. Collaboration with aerospace engineers at NASA Ames Research Center (ARC), Moffett Field, CA, and Raytheon<sup>2</sup> during the design phase resulted in an airworthiness precertification prior to any component fabrication. The above design management techniques, increasingly practiced throughout the aerospace industry, minimized manufacturing errors and fabrication time.

Due to manpower limitations at NASA/ARC as well as the need to refine the PSR design, the August flight window could not be met. However, the design and fabrication effort culminated in a design that was subsequently fabricated and assembled on a less intensive schedule during the period from June 1995 through April 1996. The azimuthal and elevational scanning capabilities of the PSR were first demonstrated in May 1996. During this month the PSR was also fit to the NASA DC-8 nadir-7 window in preparation for future aircraft flights, and an on-site airworthiness inspection was performed. No significant deficiencies were found in the mechanical or aerodynamic attributes of the PSR. Currently, the PSR is more than 90% flight-ready, with some cabling, receiver and correlator installation, calibration load fabrication, and flight software yet to be completed.<sup>3</sup>

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<sup>2</sup> The Raytheon group consisted of J. Baloun, M. Tucker, and R. Davidson, and were primary subcontractors to NASA Ames Research Center regarding experiment integration on NASA medium altitude aircraft.

<sup>3</sup> For further details on the PSR see Appendices A and C, or Piepmeier and Gasiewski, 1996b.

The PSR was originally designed for airborne deployment on primarily the NASA DC-8. To provide additional platform diversity, re-integration of the PSR in the bomb bay of the NASA Wallops Flight Facility's P-3B for the Labrador Sea Experiment was begun in May 1996. The Labrador Sea experiment along with associated integration flights will comprise the first in-flight demonstrations of the PSR. Additional plans for integration of the PSR into the Q-bay of the NASA ER-2 aircraft have been outlined. The ER-2 platform would allow high-altitude (65,000 ft, or 20 km) operation that would be especially suitable for simulation of satellite observations of ocean surface winds, cloud ice, and convective precipitation. Initial cost estimates for this integration are considerable (\$325,000) due to the need for extensive modification of a Q-bay hatch cover. Simpler and less-expensive integration designs are currently being considered for the ER-2 integration.

#### A. PSR Design Objectives, Constraints, and Results

The PSR design followed directly from specific scientific objectives along with platform and mechanical constraints, culminating in an extremely versatile scanning instrument. The scientific objectives of the PSR were: (1) to provide fully polarimetric (four Stokes' parameter:  $T_v$ ,  $T_h$ ,  $T_u$ , and  $T_v$ ) observations of thermal emissions from the ocean surface at four of the most important frequencies (10.7, 18.7, 37.0, and 89.0 GHz), thus providing measurements from X to W band; (2) to provide absolute measurement accuracy for all four Stokes parameters for each frequency of better than 1 K for  $T_v$  and  $T_h$ , and 0.1 K for  $T_u$  and  $T_v$ ; (3) to provide radiometric imaging with fore and aft look capability (rather than single spot observations or aircraft circle observations); (4) to provide conical, cross-track, along-track, and spotlight mode scanning capabilities; and (5) to provide imaging resolutions appropriate for both resolving long ocean waves and for simulating satellite observations with Nyquist spatial sampling.

Constraints on the design were dictated by the available platforms and the associated mechanical, aerodynamic, and environmental considerations. The NASA DC-8 was chosen as the primary platform due to its extensive range, altitude and payload capabilities. Moreover, designing the PSR to fit into the nadir-7 port of the DC-8 would allow simple retrofits to other aircraft, for example, the NASA P-3B, NASA C-130Q, NRL P-3, and NASA ER-2. Accordingly, the DC-8 design

specifications of 6 g's and an aerodynamic Q of 570 psf (during dive) were used. Environmental conditions to be considered included an operating temperature range of -40°C to 40°C, condensing atmosphere, and nominal aircraft vibration levels.

The resulting design (see Figures 1-3; see also Appendix C for a diagram listing) was conceived during the period from March through June 1995. The PSR scanhead consists of four polarimetric radiometers operating at 10.7, 18.7, 37.0, and 89.0 GHz. To efficiently utilize the scanhead faceplate space, the 10.7 and 37.0 GHz radiometers utilize a common dual-band antenna (Figure 4), while the 18.7 and 89.0 GHz receivers each utilize their own single-band antennas. All antennas are of the lens/corrugated feedhorn type, and manufactured by Microwave Engineering Corporation of North Andover, MA.<sup>4</sup> All antennas are dual orthogonal-linear polarized, with on-axis cross-polarization ratios better than 30 dB. The microwave receivers are all dual-channel superheterodyne with a common local oscillator driving each of two identical mixers (Figure 5). The 10.7 and 18.7 GHz receivers are single sideband (SSB) and use high electron mobility transistor (HEMT) preamplifiers, while the 37.0 and 89.0 GHz receivers are double sideband (DSB). Noise temperatures are low enough to meet the required sensitivities for most aircraft imaging modes (see Appendix A).

Calibration will be performed in-flight using standard (unpolarized) hot and cold blackbody targets, with absolute polarimetric calibration accomplished on the ground using a polarized calibration load [Gasiewski and Kunkee, 1993]. In order to use unpolarized loads to calibrate the system, an innovative digital correlator for polarimetric radiometry was developed [Piepmeier and Gasiewski, 1996a; see also Appendix B].<sup>5</sup> Each of eight correlator cards processes a 500 MHz bandwidth; IF subband division is used to provide the total IF bandwidth needed to meet the sensitivity requirements. The correlators operate at 1 GS/sec and are implemented using high-speed emitter-coupled logic (ECL) and digital-microwave design techniques (Figure 6). The digital correlators are

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<sup>4</sup> The antennas are based on similar design as that used on the DMSP SSM/I instrument.

<sup>5</sup> The development of the digital correlator hardware is supported under NASA Headquarters grant NAGW-4191, "Passive Measurement and Interpretation of Polarized Microwave Brightness Temperatures."

backed up by redundant conventional analog detection systems.

Figure 7 shows the performance of the digital correlating radiometer (operating at 400 MS/sec) viewing a rotating polarized calibration load. It is seen that the feedhorn brightness temperatures ( $T_{fA}$ ,  $T_{fB}$ ,  $T_{fU}$ ) and the Stokes' parameters of the load ( $T_v \approx 332$ ,  $T_h \approx 309$ ,  $T_u \approx 0$  in Kelvins) follow the well known rotational transformation relationship [Tsang et al., 1985]:

$$\begin{pmatrix} T_{fA} \\ T_{fB} \\ T_{fU} \end{pmatrix} = \begin{bmatrix} \cos^2 \phi & \sin^2 \phi & \frac{1}{2} \sin 2\phi \\ \sin^2 \phi & \cos^2 \phi & -\frac{1}{2} \sin 2\phi \\ -\sin 2\phi & \sin 2\phi & \cos 2\phi \end{bmatrix} \cdot \begin{pmatrix} T_v \\ T_h \\ T_u \end{pmatrix}$$

where  $\phi$  is load rotation angle around the feedhorn axis. The minimum theoretical sensitivity (i.e., SNR) for a digital correlator is ~81% of the SNR for a perfect analog correlator. The measured sensitivity of the digital correlator for  $T_u$  is approximately a factor of two below the minimum theoretical level. The reduction in sensitivity is apparently due to digital crosstalk and is being addressed in a third-generation design using a multilevel PC board.

Unlike active instruments, radiometers have no ability to "range gate" brightness signatures caused by aircraft radomes, thus no radome is used. To provide the required imaging capabilities a nadir-viewing two-axis gimbal mount was designed and fabricated for operation in the airstream outside the aircraft (Figure 8). The mount utilizes a 30-inch diameter ring bearing to support a nominal aerodynamic load of up to 600 lbs. An aerodynamic fence is required on the NASA DC-8 to reduce the maximum free-stream wind loading to ~170 psf, which is appropriate for the gimbal and scanhead structure. Geared stepper motors with ~135 N-m of torque along with 12-bit absolute position encoders facilitate scanhead motion under nominal wind loading. Structural torsional deflections were designed to be under  $0.01^\circ$  to maintain positioning accuracy. Aircraft-quality hardware and material stock were used throughout. Azimuthal and elevation slip rings provide power to the scanhead.

Data is processed by a 80486-based computer within the scanhead, then sent to an archival computer in the aircraft cabin via a 10-base 2 LAN link through the sliprings. Thus, all radiometric detection is accomplished inside the scanhead drum. In order to minimize damage to the electronics caused by condensation, a dry nitrogen gas system is used to purge the scanhead drum and sliprings. A polarized red-filtered video camera is also mounted inside the scanhead. This camera is used to observe the scene for purposes of cloud clearing, foam coverage estimation, and surface feature detection. The video signal is sent to a video recorder in the aircraft cabin via sliprings.

### C. PSR Applications

The gimbal-mounted PSR scanhead has simultaneous elevational and azimuthal scanning capability. Several scan modes with potential application from space will be available by in-flight software selection, including: (1) conical one- and two-look imaging modes, (2) cross-track imaging mode, (3) along-track scanning mode, and (4) spotlight mode. These scan capabilities, along with the multiband polarimetric sensing capability of the PSR the following applications:

- Ocean thermal emission model function validation
- Wind-vector two-look retrieval algorithm development
- Resonant thermal emission studies
- SSMI/S, TRMM, NPOESS calibration/validation
- Incident angle measurements for convergence studies
- Precipitation and cloud parameter retrieval algorithm studies
- Joint observations with SAR, wind lidar, and scatterometers
- Internal wave/surface interaction studies
- Marine boundary layer studies
- Multispectral ocean and land ice studies
- Detection and imaging of oil slicks
- Tower and ship based observations

When operating in conical scanning mode the beam incident angle will be variable from 0 degrees (nadir) to 70 degrees above nadir to allow assessment and optimization of several candidate wind-direction retrieval techniques. In addition, replacement of any of the four radiometers with other

active or passive instruments (of appropriate size and weight) can be done to extend or modify the capabilities of the PSR.

#### D. PSR Deployments

The PSR was originally designed for airborne deployment on primarily the NASA DC-8. A successful fit to the DC-8 nadir-7 port took place at the NASA Ames Research Center in May 1996 (Figure 3), although test flights on the DC-8 currently await the installation of an aerodynamic fence.<sup>6</sup> Deployments of the PSR on the DC-8 are being planned for the middle of 1997.

In January 1997, the first airborne deployments of the PSR are planning to be conducted over an instrumented site in the Labrador Sea (around 56°N 52°W).<sup>7</sup> These deployments will emphasize ocean surface imaging of the four Stokes' parameters. The primary goals of the Labrador Sea experiment will be to (1) develop optimal strategies for the retrieval of the oceanic wind vector and (2) to develop a physically-based thermal emission model function for the ocean surface. In addition, wind vector retrievals using the PSR will be used to aid in calibration/validation studies of the NSCAT wind scatterometer, to be launched in August 1996. The deployment will take place with the PSR mounted in the "bomb-bay" of the NASA/WFF P-3B aircraft. Integration of the PSR into the P-3B bomb-bay is currently underway.

During January the Labrador Sea is an area of extremely high surface winds, often exceeding 15 m/sec. Overflights of an instrumented drifter buoy array (MINIMET array) operated by P. Niiler of the Scripps Institution of Oceanography are expected to provide the following sea surface and atmospheric parameters: surface pressure, sea surface and air temperature, and wind speed and

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<sup>6</sup> Manpower limitations at the NASA Ames Research Center during FY1996 have delayed the installation of the PSR fence on the DC-8 until late 1996 at the earliest.

<sup>7</sup> Deployments of the PSR in conjunction with the Labrador Sea experiment will be partially supported under ONR grant N00014-95-1-0426, "Airborne Measurements of Oceanic Wind Vector Fields over the Labrador Sea using Passive Polarimetric Radiometry." Additional support will be provided by NASA Headquarters grant NAGW 4191 and project order number SMC185-96-N0109 from the NPOESS Integrated Program Office.



direction. An instrumented mooring provided by the D. Pillsbury of the Oregon State University will provide independent data on these parameters as well as additional data on long-wave directional spectra. Wind dropsondes for in-flight measurement of wind profiles from the P-3B are to be provided by G. Albright of the National Center for Atmospheric Research (NCAR). Additional instruments to be flown on the P-3B include the University of Massachusetts C-band scatterometer (C-Scat) and several non-scanning polarimetric radiometers from NASA/JPL, NRL (the Windrad suite), and the NOAA/ETL. The integration and flight logistics for the Labrador Sea experiment are being managed by P. Bradfield of the NASA Wallops Flight Facility.

## CONCLUSIONS AND RECOMMENDATIONS

On the basis of laboratory measurements of thermal emission over water waves [Gasiewski and Kunkee, 1994; Johnson et al., 1993, Yueh et al., 1995], SSM/I satellite measurements over the ocean [Wentz, 1991; 1992], and theoretical modeling studies of ocean thermal emission [Kunkee and Gasiewski, 1996] it appears that it is possible to perform satellite-based measurements of ocean surface wind direction using polarimetric radiometry. Moreover, the addition of a cross-correlation channel to measure  $T_U$  will provide independent and unique information on the direction of surface wind. In order to develop practical retrieval techniques for passive measurement of wind direction it is important that the model function for thermal emission from a striated ocean be more fully developed. This task can be greatly facilitated via collection of in-situ ocean thermal emission data for a variety of conditions from aircraft.

The PSR will allow passive polarimetric observations of the ocean surface from the NASA DC-8 or P-3 platforms over a wide range of incidence angles. The gimbal mount scanning mechanism will allow the four PSR radiometers (at frequencies of 10.7, 18.6, 37.0, and 89.0 GHz) to view the surface at elevation angles from nadir up to  $70^\circ$ , and over  $360^\circ$  in azimuthal angle.<sup>8</sup> Thus, two-look algorithms for ocean wind direction sensing will be able to be thoroughly tested prior to space instrument definition. A variety of scan modes will be available: cross-track, along-track, spotlight, and conical. In the conical mode, incidence angles from zero to  $70^\circ$  will be selectable in-flight via software.

The broadband nature of the PSR channel set will greatly facilitate the collection of a data set for corroborating a thermal emission model function of the ocean surface. The PSR channels will also coincide with critical channels used by the SSM/I, SSM/I-S, and TRMM Microwave Imaging Instrument (TMI), and converged DoD/NOAA/NASA instruments. Thus, the PSR is expected to

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<sup>8</sup> The elevation angle of the PSR forward view on the DC-8 is limited to 53 degrees due to occultation caused by the aircraft faring. The PSR P-3 integration will avoid this forward occultation, thus providing a full  $360^\circ$  view up to  $70^\circ$  above nadir.

be a valuable underflight instrument for calibration and validation studies involving these sensors.

Due to their wide altitude range (500 m to 8 km for the P-3B, and 500 m to 12 km for the DC-8) and exceptional attitudinal stability, these aircraft are excellent platforms for ocean surface emission studies. However, the PSR channel set and polarimetric capabilities can also be used for studies of atmospheric convection. In atmospheric convection studies, it is desirable to obtain platform altitudes up to 20 km in order to observe the highest cell tops. Such altitudes can be obtained by the NASA ER-2 high-altitude aircraft. Thus, in the third grant year it is recommended that integration of the PSR on the NASA ER-2 be further considered with the goal of reducing the integration cost to ~\$200,000.

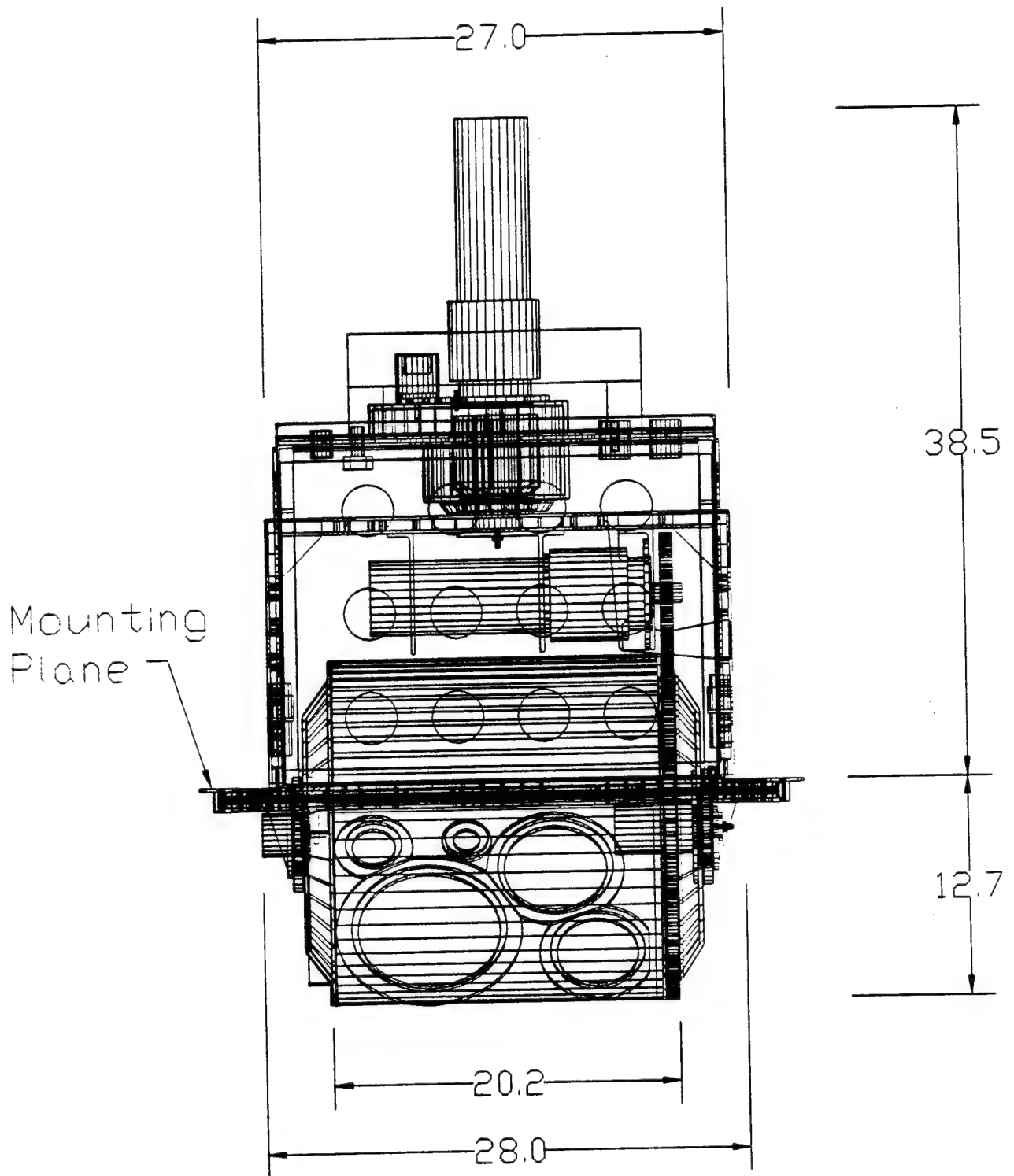


Figure 1a. PSR Autocad rendering showing critical dimensions (in inches) - front view.

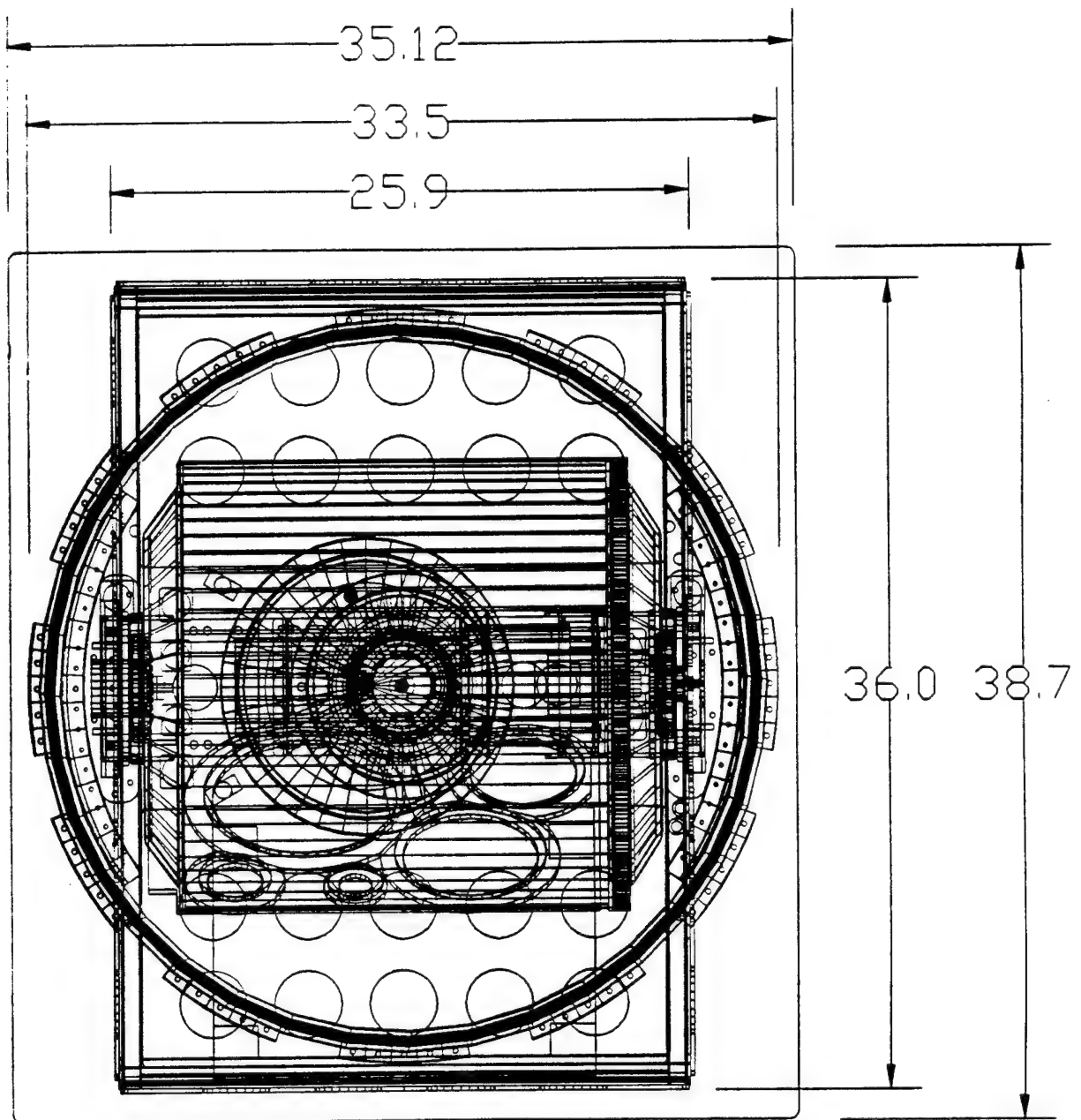


Figure 1b. PSR Autocad™ rendering showing critical dimensions (in inches) - top view.

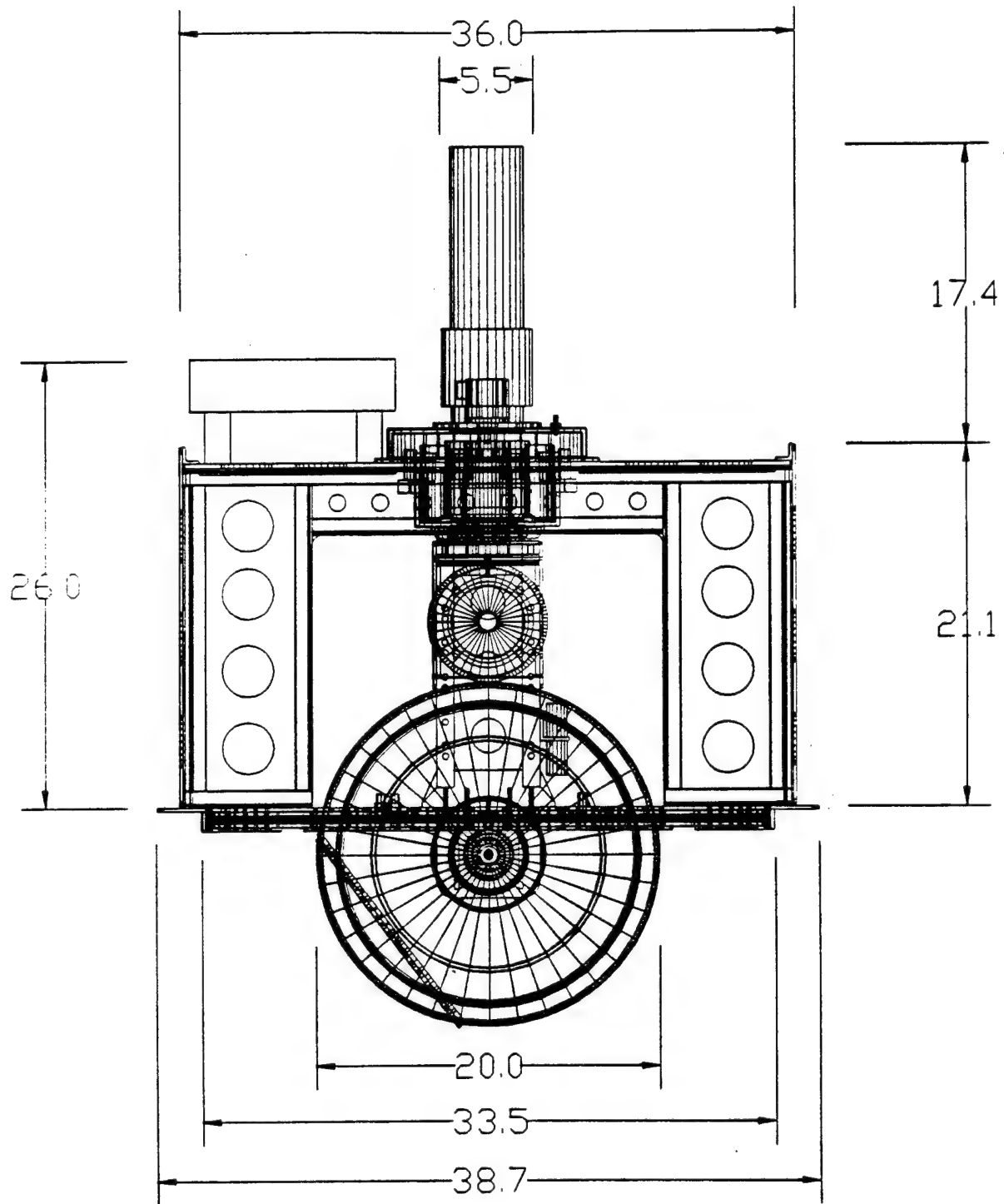


Figure 1c. PSR Autocad™ rendering showing critical dimensions (in inches) - side view.

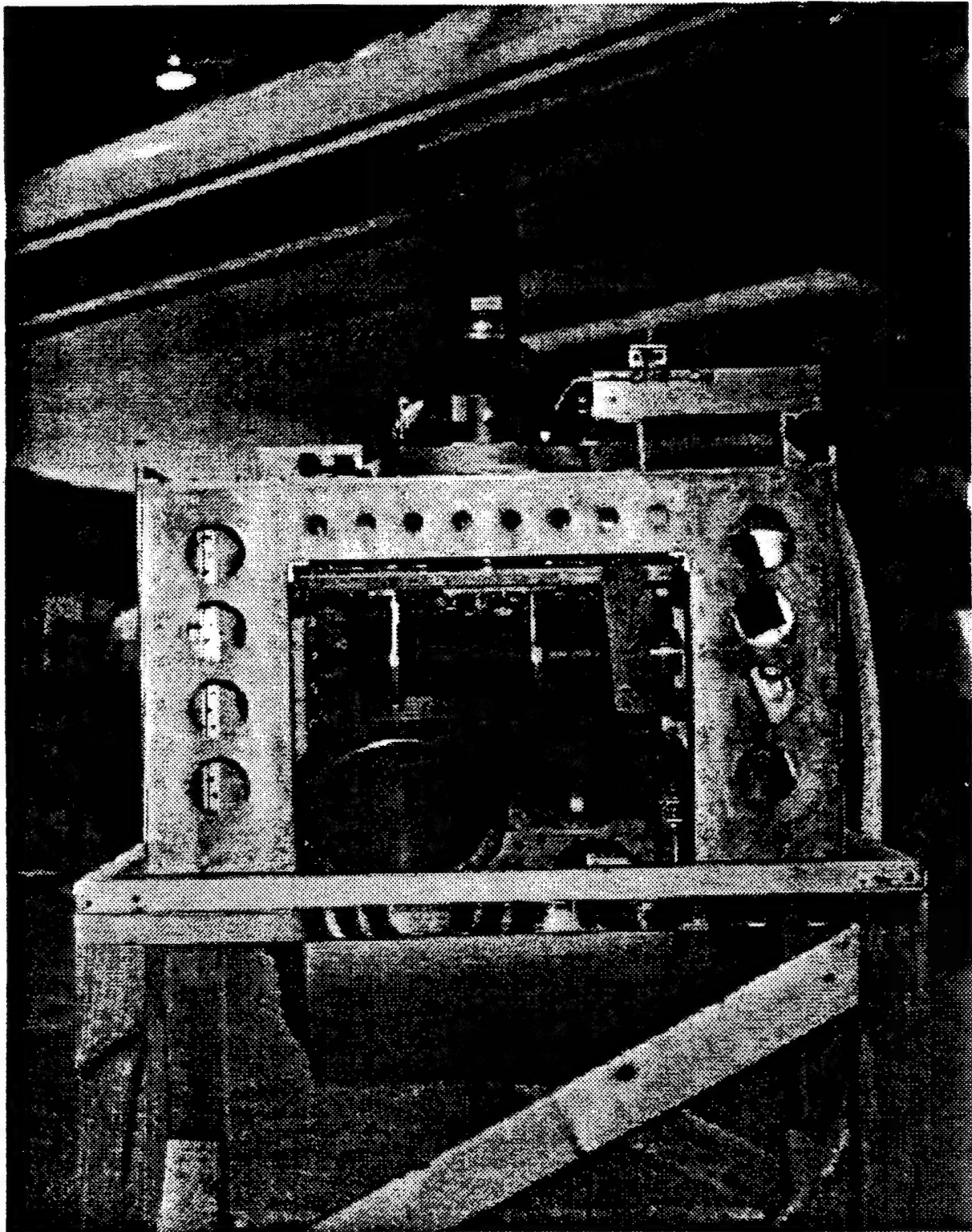


Figure 2. Photograph of the PSR - side view.

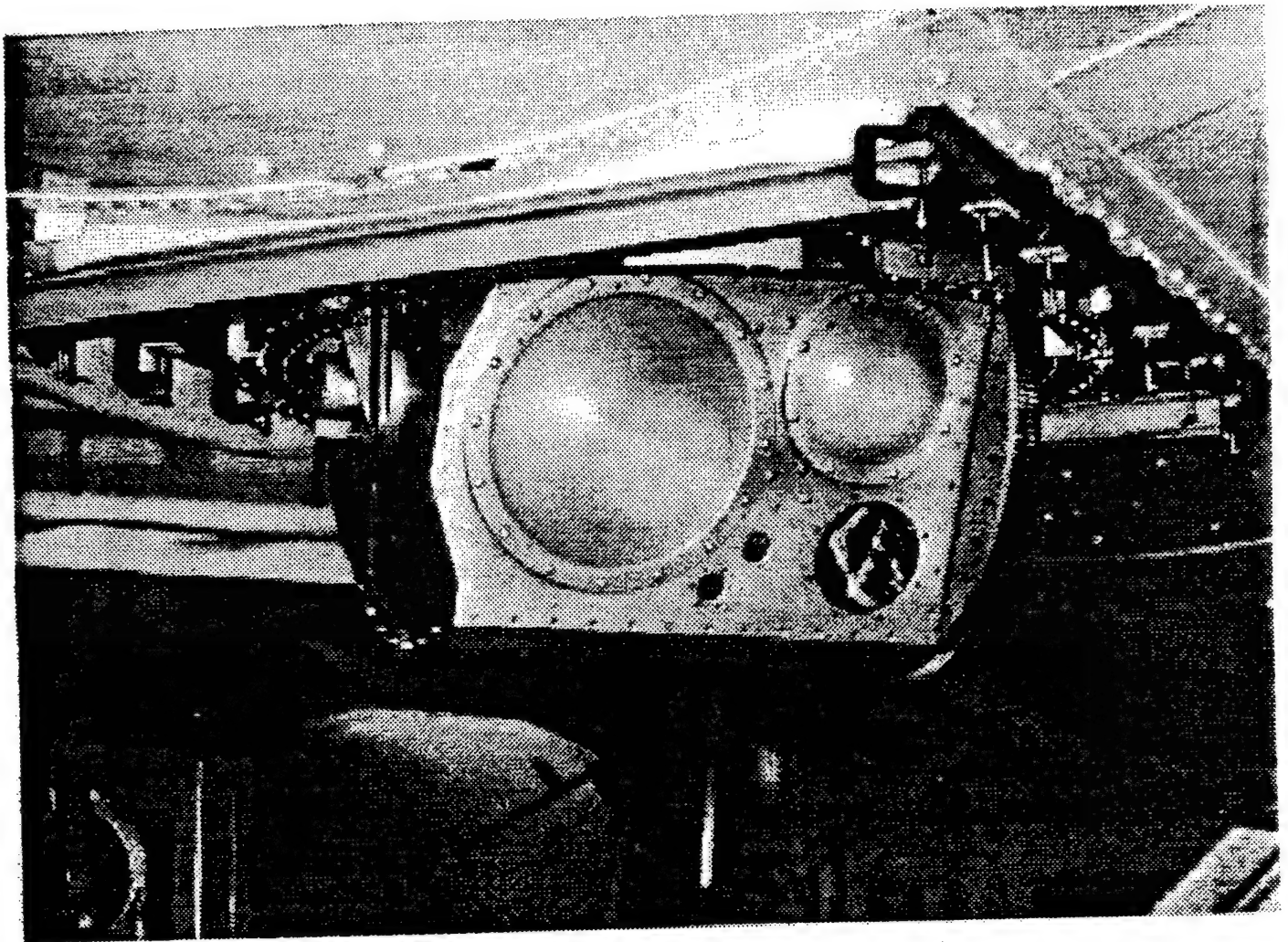


Figure 3. Photograph of PSR integration into the nadir-7 port of the NASA DC-8 aircraft.





Figure 4. 10.7 / 37.0 GHz dual-band dual-polarization antenna with integrated lens and feedhorn.



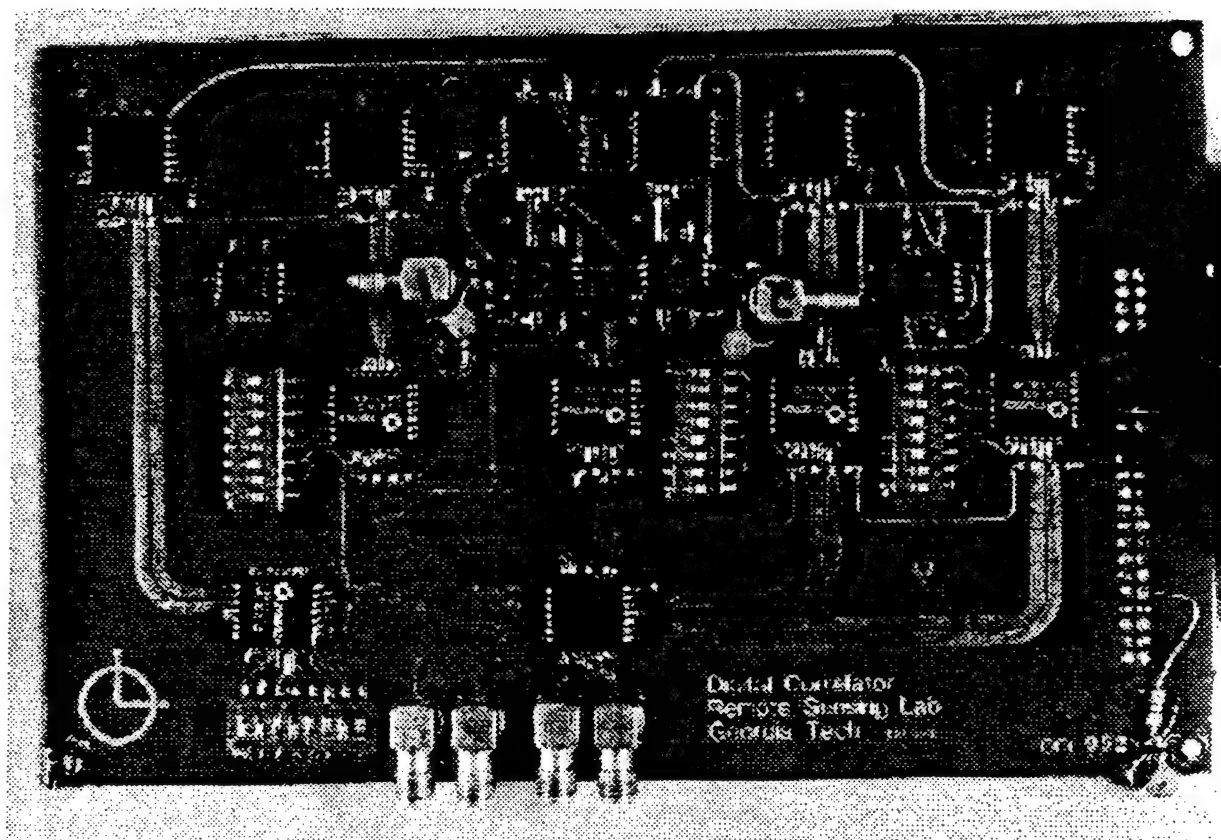


Figure 6. Photograph of the second-generation 1 GS/sec digital correlator card.

# Brightness Temperatures Orthogonal and Correlation Channels

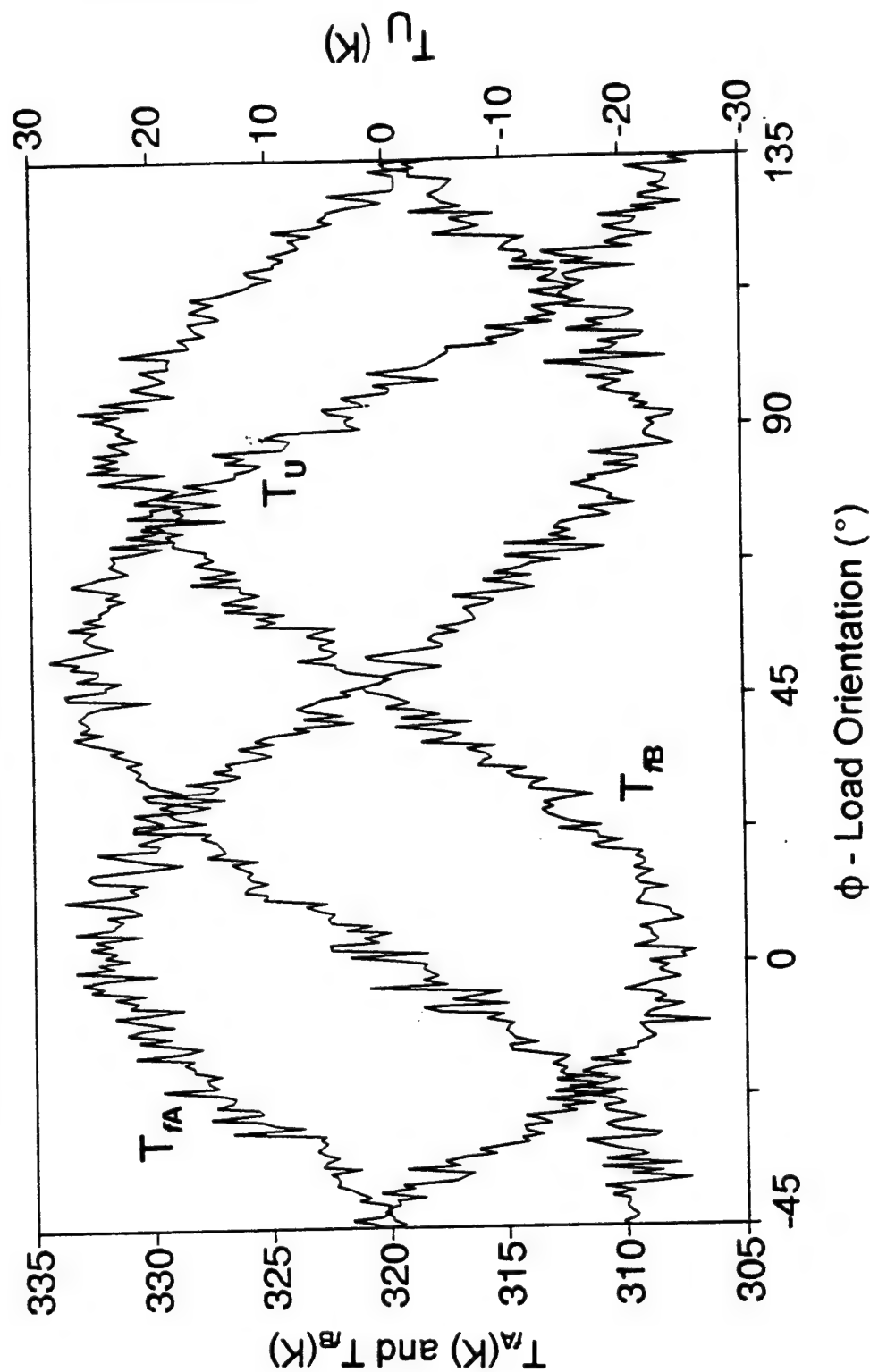


Figure 7. Variations in the first three Stokes' parameters as a function of the rotational angle of a polarized calibration load. As expected,  $T_A$  and  $T_B$  are in phase quadrature with  $T_U$ , and the amplitude of  $T_U$  is equal to the amplitudes of  $T_A$  and  $T_B$ .

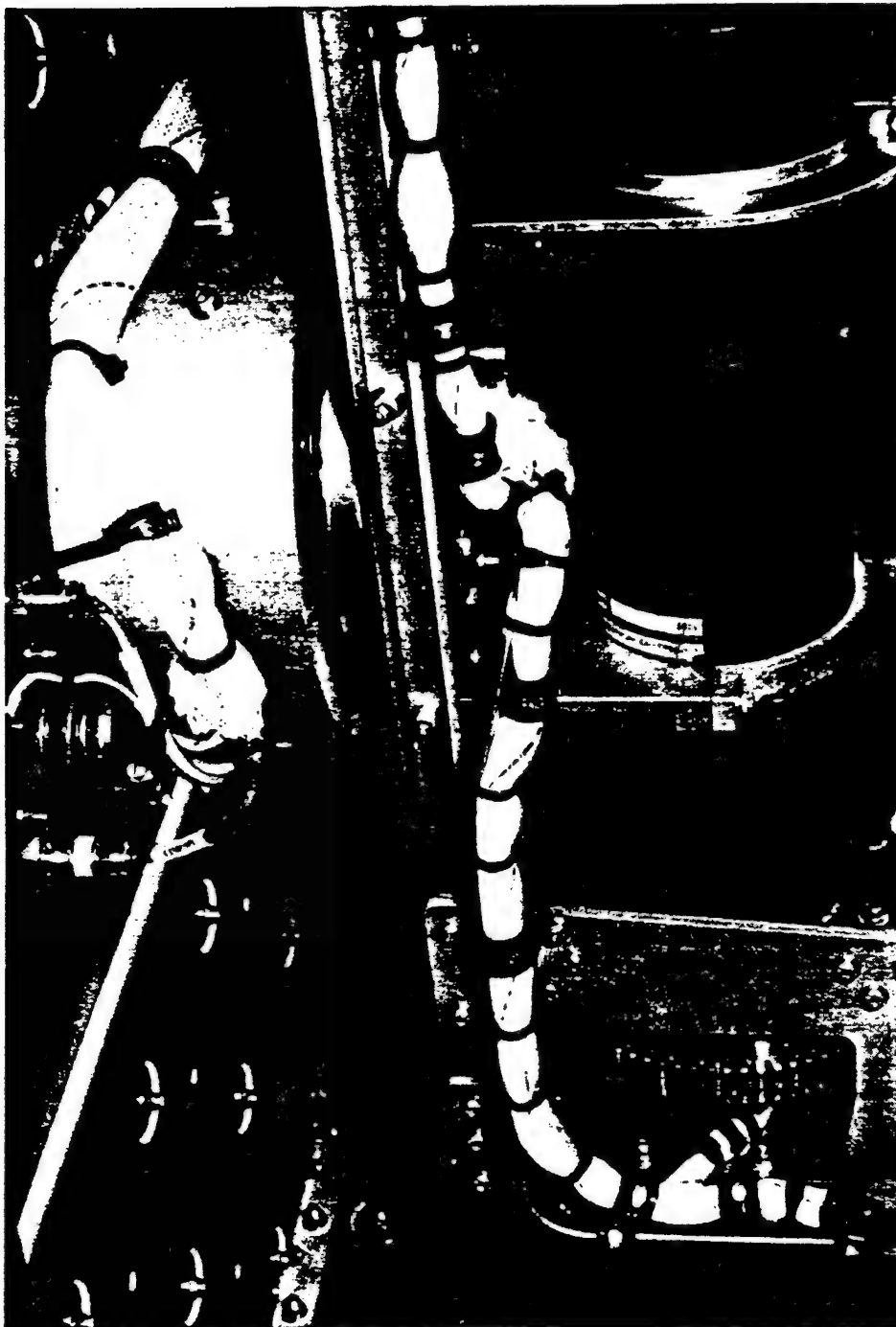


Figure 8. Close up photo of the PSR yoke and upper azimuthal bearing assembly illustrating part of the gimbal scanning mechanism. The elevation scan motor and elevation drive gear are shown.

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## Polarimetric Scanning Radiometer for Airborne Microwave Imaging Studies

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**Abstract** - A multiband microwave polarimetric scanning radiometer (PSR) has been constructed for airborne observations from the NASA DC-8 airborne platform. The primary application of the PSR is the development of optimal spaceborne hardware configurations and retrieval algorithms for passive wind-vector sensing over the ocean surface. Four radiometers, operating at 10.7, 18.7, 37, and 89 GHz, each measure the first three modified Stokes' parameters ( $T_v$ ,  $T_h$ , and  $T_U$ ). A gimballed mechanism allows observations at any incident angle within a cone of  $\sim 70^\circ$  half-angle around nadir. The PSR's four radiometers and two-axis scanning capability will provide unique polarimetric data for microwave emission studies of both ocean and land surfaces, as well as atmospheric clouds and precipitation.

### 1. INTRODUCTION

Airborne remote sensing instruments can provide critical data needed for spaceborne sensor and retrieval algorithm development. Given the recent mandates for low-cost Earth probes, airborne measurements have become all the more important to such development. Indeed, for only a small fraction of the cost of a comparable spaceborne system, an airborne sensor can provide a wealth of data for determining the optimal configuration of spaceborne hardware and geophysical estimation algorithms. We describe here a new instrument for passive microwave remote sensing from airborne platforms which provides several unique capabilities. The Polarimetric Scanning Radiometer (PSR) was developed to provide wideband spectral coverage with tri-polarimetric (three Stokes' parameter) capability using a variety of scan modes. The primary application of the PSR is the development of optimal hardware configurations and retrieval algorithms for passive wind-vector sensing over the ocean surface. Additional applications include high-resolution polarimetric imaging of clouds, convective precipitation, sea ice, and (to a lesser degree) soil moisture.

### 2. INSTRUMENT DESCRIPTION

This work was supported by ONR grant N00014-95-1-0426, NASA grant NAGW 4191, and the Georgia Institute of Technology.

The PSR consists of four gimbal-mounted radiometers operating at 10.7, 18.7, 37, and 89 GHz (Figure 1). Each radiometer measures the first three modified Stokes' parameters ( $T_v = \langle |E_v|^2 \rangle$ ,  $T_h = \langle |E_h|^2 \rangle$ , and  $T_U = 2\text{Re}(E_v E_h^*)$ ). Analog detection hardware is used to measure the orthogonal brightness temperatures,  $T_v$  and  $T_h$ . A recently developed three-level digital correlator operating at 1 GS/s has been implemented for the measurement of  $T_U$ . This combination of receiver/detector technology allows precise calibration using only two (hot and cold) non-polarized calibration standards.

A dual-band feedhorn antenna with integrated lens provides 3-dB beamwidths of  $8^\circ$  and  $2.3^\circ$  at 10.7 and 37 GHz, respectively. The antenna uses a corrugated scalar feedhorn along with a grooved rexolite lens. Orthomode couplers are used to obtain the orthogonally-polarized signals. Two similar single-band lens/feedhorn antennas operating at 18.7 and 89 GHz have 3-dB beamwidths of  $8^\circ$  and  $2.3^\circ$ , respectively. These beamwidths correspond to nadir spot sizes from 200 to 700 meters when operated at a nominal altitude of 5 km. Polarization isolation within the principal planes is typically better than 30 dB. While conventional double sideband superheterodyne radiometers are used for the 37 and 89 GHz channels, single sideband receivers with HEMT front-end amplifiers are used for the 10.7 and 18.7 GHz channels. Other important radiometric specifications are provided in Table 1. The block diagram for the typical PSR radiometer is shown in Figure 2.

The digital correlators are comprised of three basic components: (1) high-speed analog-to-digital converters (ADC), (2) three-level multipliers, and (3) ripple accumulators. The baseband radiometer signals are sampled and quantized into three levels at  $10^9$  samples per second. Following discretization, the signal samples are multiplied and the resulting products are accumulated in a 24-bit ripple counter. The accumulated value is converted into an estimated analog correlation coefficient using methods presented in [1]. With the appropriate threshold levels, the three level correlator achieves a sensitivity of  $\sim 0.81$  relative to a perfect analog correlator [2].

The correlators use discrete high-speed ECL components to achieve a fast sampling rate and wide bandwidth. The high-speed ECL signals exhibit transition times of

$\leq 250$  ps; therefore, the digital signals have spectral content  $\geq 4$  GHz. The circuit is fabricated on low-loss woven PTFE double-sided copper-clad circuit board. All high-speed components (both passive and active) are surface mount devices. Microstrip transmission lines with terminating resistors form signal interconnections. The use of such microwave digital design techniques eliminates ringing and minimizes transition time, thus maximizing the correlator bandwidth. When sampled at the Nyquist rate, each correlator measures an IF band of width 500 MHz. The use of several correlators along with IF sub-band splitting hardware provides a total IF channel bandwidth equal to a multiple of the bandwidth for a single correlator.

The PSR gimbal structure allows the radiometer antennas to be scanned in-flight using two independent degrees of freedom (azimuth and elevation). The mechanism permits a number of scanning modes, including conical, cross-track, and spot-light modes. These scan modes may include any observation angle within a cone of  $\sim 70^\circ$  half-angle around nadir. (A fence is located in front of the instrument to reduce wind loading; this fence limits the direct forward view to  $\sim 53^\circ$  from nadir.) A programmable controller operates two sealed, low-temperature stepper motors with position feedback obtained using two 12-bit optical encoders providing  $0.088^\circ$  pointing knowledge.

Electrical power is supplied to the instruments in the drum via slip-rings, thus allowing continuous rotation of the radiometer drum in both axes. Maximum motor torque is  $\sim 75$  N·m (100 ft·lbf), providing a minimum scan rate of one line every three seconds. Passive motor brakes are used to prevent windmilling in the event of power loss.

Calibration of the PSR is accomplished by viewing two unpolarized blackbody standards, one at ambient temperature ( $\sim 250$  K) and one heated to  $\sim 310$  K. Each standard consists of absorber material fastened to a metal heat sink and contained within a closed-cell styrofoam insulating jacket. Using the digital correlator, only two such calibration standards (hot and cold) are needed to calibrate both the total power channels ( $T_v$  and  $T_A$ ) and the cross-correlating channel ( $T_U$ ). Blackbody temperatures are measured at eight locations on each standard using RTD sensors embedded in the absorbing material. The scanhead drum, slip rings, and calibration loads are purged in-flight with dry nitrogen to protect the radiometers, electronics, and other sensitive materials from water vapor and condensation.

Radiometric data is collected by a computer located within the scanning drum. This remote system communicates with the main computer via a 10-base-2 local area network. The main computer system, used for interac-

tive experiment control and data logging, is located in the cabin of the aircraft. Temperature data from the calibration standards is stored in a RAM cache and transferred via an RS232 interface for storage by the data acquisition system. Data from the various sources are time-stamped using time generators synchronized to IRIG-B signals, thus facilitating precise temporal registration. A video camera is located within the scanhead and co-boresighted with the radiometer antennas.

### 3. APPLICATIONS

Dual-polarized radiometer data from the DMSP SSM/I instrument has been shown to be useful for the measurement of the oceanic wind vector [3]. Recently, the utility of  $T_U$  was experimentally observed by [4, 5]. Specifically, azimuthal brightness variations of  $T_U$  were shown to be similar in amplitude to those of  $T_v$  and  $T_A$ , but in phase quadrature.  $T_U$  appears to be relatively insensitive to unpolarized emissions from clouds. The paucity of available polarimetric data, however, has hindered the development of an optimal passive wind-vector sensor. The PSR is unique in that it is the first aircraft instrument designed to both verify and help improve passive wind vector sensing techniques applicable to spaceborne observation systems. Importantly, images of the upwelling Stokes parameters can be made over a wide microwave frequency range (X- to W-band) with channels comparable to the SSM/I, SSM/I-S, and EOS MIMR sensors, and over a wide range of surface incident angles. Thus, the conically scanned imagery from the PSR will be critical to both the development of wind vector retrieval algorithms and the optimal configuration for a spaceborne wind vector sensor.

Since the launch of the first SSM/I in 1987, this instrument has been used to map convective precipitation rate, cloud liquid water, ice content, and integrated water vapor, along with sea surface parameters. Improvements in global equatorial coverage could be obtained using a slightly wider cone-angle than provided by the SSM/I. The requirement of global equatorial coverage at the SSM/I altitude of 833 km in turn requires a greater surface incident angle ( $\sim 63^\circ$ ). Underflights of the SSM/I using the PSR will be useful in assessing the impact of such an increase in the angle of incidence on the accuracy of the above retrieved parameters. In addition, the PSR will be useful as a post-launch underflight sensor for calibration and validation purposes.

### 4. SUMMARY

PSR components are currently being assembled at the Georgia Institute of Technology, with initial flights being



planned for May-June, 1996. A second set of lights focussing on passive wind vector sensing is being planned for January 1997 over the Labrador Sea area. With its multispectral polarimetric measurement capabilities the PSR will provide important data necessary for the development of passive wind-vector sensing techniques. Future deployments of the PSR are being planned in conjunction with the NASA Tropical Rainfall Measurement Mission (TRMM) and with calibration/validation studies in support of the National Polar-Orbiting Operational Environmental Satellite System (NPOESS).

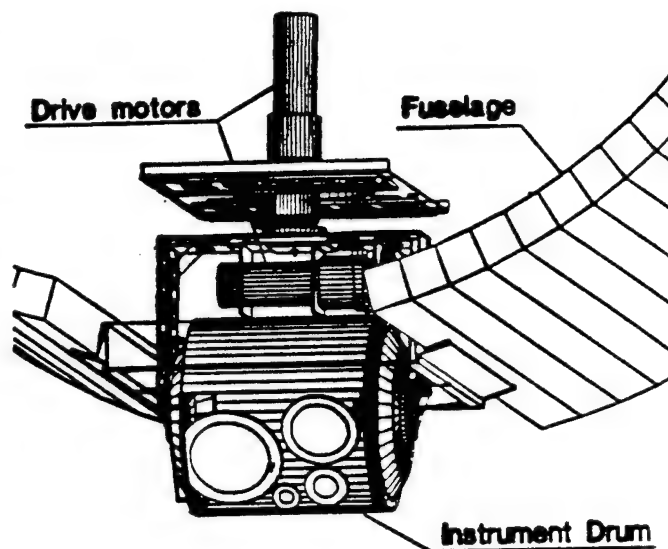
**Acknowledgements:** The authors would like to thank R. Davidson, J. Baloun, and M. Tucker of the Raytheon Corporation; C. Campbell, E. Panning, D. Kunkee, E. Thayer, and S. Sharpe of the Georgia Institute of Technology for valuable contributions to the design of the PSR; and Dr. M. Van Woert of the U.S. Office of Naval Research for his support.

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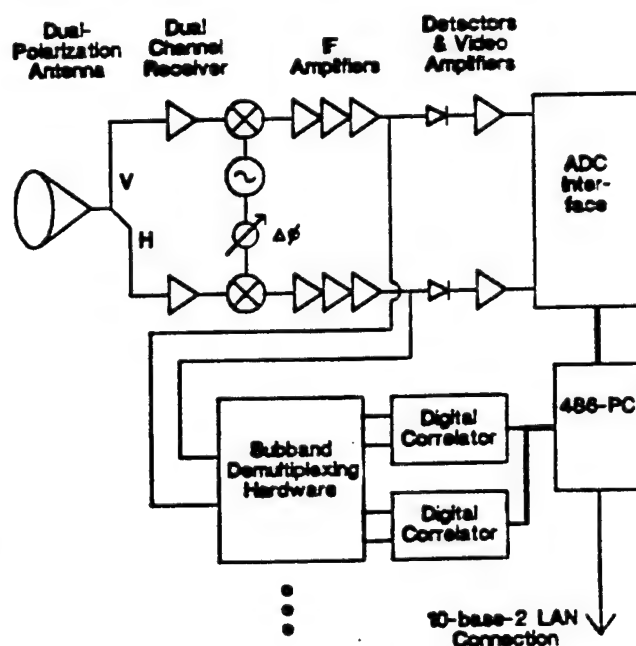
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- [5] A. J. Gasiewski and D. B. Kunkee, "Polarized microwave emission from water waves", *Radio Sci.*, vol. 29, no. 6, pp. 1449-1466, December 1994.

**Table 1. Radiometer specifications**

Band	K	K <sub>a</sub>	K	W
Frequency (GHz)	10.4-10.8	18.4-19.0	84-86	84-92
Receiver type	SSB/HEMT	SSB/HEMT	DSB/LO	DSB/LO
IF bandwidth (MHz)	400	500	1000	2000
Receiver temp. (K)	390	390	550	600
Sensitivity (K) for 10 ms integration	0.24	0.29	0.37	0.34
3-dB beamwidth	8°	8°	3.3°	3.3°
3-dB spot size (km) at 8 km altitude:				
nadir	0.70	0.70	0.30	0.20
53° incidence	1.1 X 1.9	1.1 X 1.9	0.32 X 0.55	0.32 X 0.55



**Figure 1:** Three-dimensional CAD rendering of PSR illustrating instrument drum and gimbal mount. Support structure has been removed for clarity.



**Figure 2:** Block diagram of the typical PSR radiometer.

## THREE-LEVEL 1 GS/s DIGITAL CORRELATOR FOR WIDEBAND POLARIMETRIC RADIOMETRY

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### ABSTRACT

A 500-MHz bandwidth, three-level (1.6 bit) digital correlator operating at 1 GS/s was designed and fabricated. The digital circuit is comprised of discrete high-speed silicon emitter-coupled logic components. The use of digital microwave design techniques was necessary to accomplish proper clock distribution, impedance matching, and asynchronous signal propagation. The correlator is to be part of a fully polarimetric radiometer for airborne application. Experimental results from a 400 MS/s prototype polarimetric radiometer are presented.

### INTRODUCTION

Wideband high-speed digital correlators have applications in radiometric polarimetry, synthetic-aperture interferometric radiometry, and autocorrelation spectroscopy. Previously, such correlators were fabricated using either VLSI or standard ECL and operated at sampling rates  $\leq 256$  MS/s [1], [2]. The correlator described herein uses discrete high-speed ECL

components to achieve a significantly faster sampling rate and wider bandwidth. Digital microwave design techniques were applied in the development to attain proper operation of the correlator at up to 1 GS/s clock rates.

### DIGITAL CORRELATOR

The digital correlator is comprised of three basic components: high-speed analog-to-digital converters (ADC), three-level multipliers, and ripple accumulators. The input signals are assumed to be jointly Gaussian with zero mean and unit variance. The signals are sampled and quantized into three levels at  $10^9$  samples-per-second. The effective 1.6-bit ( $\log_2 3 = 1.6$ ) ADCs are comprised of latched dual comparators clocked at  $\sim 1$  GS/s. The digitized data takes on values of +1, 0, or -1 depending on the level of the input signal with respect to positive and negative DC threshold levels. The samples are multiplied using a total of six AND/NAND gates and results are accumulated in 24-bit ripple counters. The counter value after  $2^{24}$  samples provides an estimate of the correlation coefficient of the two signals. This estimate is converted into a corresponding analog correlation coefficient using methods presented in [3]. With the appropriate threshold levels, the

three level correlator achieves a sensitivity of 0.81 relative to a perfect analog correlator [4].

## DESIGN TECHNIQUES

Use of digital microwave design techniques preserves the integrity and timing of the high-speed digital signals. The high-speed ECL signals exhibit transition times of  $\lesssim 250$  ps; therefore, the digital signals have spectral content  $\gtrsim 4$  GHz. The circuit is fabricated on low-loss woven PTFE double-sided copper-clad circuit board. All high-speed components (both passive and active) are surface mount devices. Interconnections are made using microstrip transmission lines with terminating resistors to eliminate ringing and minimize transition time.

A differential clock is distributed via coupled microstrip transmission line pairs operating in the odd-impedance mode. Programmable time delay ICs are used to compensate for small path length differences, thus synchronizing the clock, ADC latch, and digitized data signals. The use of such "wavefront processing" design techniques, the arrival times of all signals are adequately maintained.

## APPLICATION AND DEMONSTRATION

The digital correlator will be part of a fully polarimetric radiometer for airborne application (Figure 1). The radiometer directly measures the four modified Stokes' parameters [5]:

$$T_v \sim \langle |E_v|^2 \rangle$$

$$T_h \sim \langle |E_h|^2 \rangle$$

$$T_U \sim 2\text{Re} \langle E_v E_h^* \rangle$$

$$T_V \sim 2\text{Im} \langle E_v E_h^* \rangle$$

where  $E_v$  and  $E_h$  are the vertically and horizontally polarized incident electric fields and  $\langle \cdot \rangle$  denotes ensemble averaging. The input signals are downconverted using a pair of superheterodyne receivers driven by a common local oscillator (LO). The voltages at the receiver outputs,  $v_v(t)$  and  $v_h(t)$ , correspond to the received signals in the vertical and horizontal polarizations, respectively.

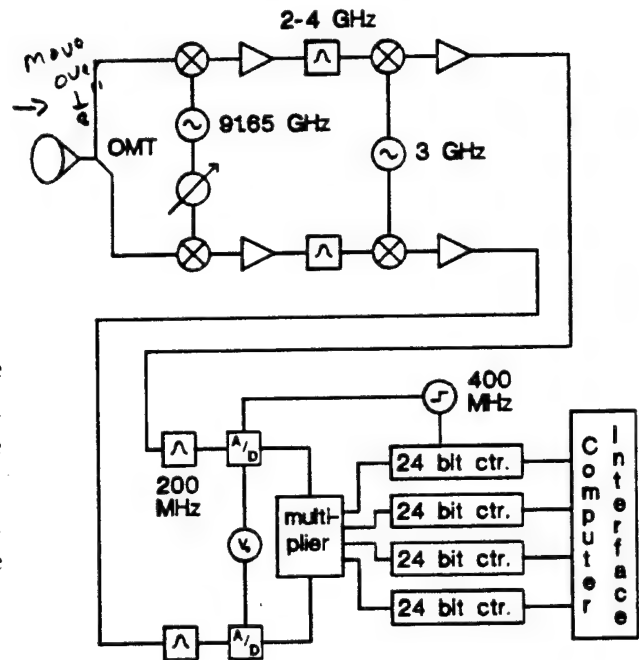


Figure 1: Digital correlator connected to a polarimetric radiometer in the polarization correlating mode.

To measure the third or fourth Stokes' parameter the correlation coefficient of the time-varying voltages  $\rho$  must be estimated by the digital correlator. These Stokes' parameters are subsequently found by:

$$T_\alpha = 2\rho_\alpha \sqrt{T_{v,sys} T_{h,sys}}$$

where  $T_{v,sys}$  and  $T_{h,sys}$  are the calibrated thermal temperatures of the two receivers (referred to the inputs) and  $\alpha = U$  or  $V$ . If the LO signal is in-phase at each of the receivers,  $T_U$  is measured; however, if  $T_V$  is desired, the LO signals are adjusted to be in quadrature-phase.

An experiment connecting a prototype digital correlator operating at 400 MS/s to a 91.65 GHz polarimetric radiometer was carried out. The radiometer was calibrated using the non-polarized hot and cold blackbody technique. A polarized blackbody described by [6] was used to generate a known input Stokes' field. Rotation of the polarized load resulted in brightness temperature variations in all three measured Stokes' parameters  $T_A$ ,  $T_B$ , and  $T_U$ . Digital measurements are converted to brightness temperatures and presented in Figure 2. As expected, the  $T_U$  variations are in phase-quadrature with those of  $T_A$  and  $T_B$ . In addition, the amplitude of the  $T_U$  variations are nearly equal to the amplitude of the  $T_A$  and  $T_B$  variations. These two features are anticipated consequences of the Stokes' parameter rotational transform [7].

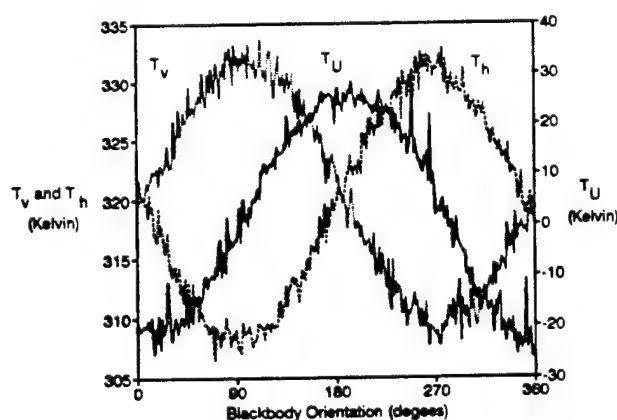


Figure 2: Brightness temperature variations for  $T_v$ ,  $T_h$ , and  $T_U$  for continuous rotation of the polarized blackbody.

## CONCLUSION

A wideband digital correlator operating at 1GS/s has been designed and built. Digital microwave design techniques were used to insure satisfactory performance. A prototype correlator operating at 400 MS/s was demonstrated in the application of wideband radiometric polarimetry.

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## Appendix C

### **PSR Drawing List**

A.J. Gasiewski  
January 25, 1996

<b>Drawing #</b>	<b>Description</b>
1.	PSR-2 Support Structure
2.	PSR-2 Structural Yoke
3.	PSR-2 Azimuthal Shaft Assembly
4.	PSR-2 Main Ring Bearing: Lower bearing inner and outer seats Inner and outer flange plates
5.	PSR-2 Endcaps Idle side Drive side Faceplate clip
6.	PSR-2 Elevation Brackets
7.	PSR-2 Electrical Wiring PSR Electrical Connectors Slipring wiring specifications
8.	TBD
9.	PSR-2 Faceplate & Lens/Feedhorn Details
10.	PSR-2 Drum/Yoke Cross-Section
11.	PSR-2 Calibration Loads
12.	PSR-2 Scanhead Interior Cutaway views of scanhead Lens/feedhorn antennas Power supply plate
13.	DC-8 Equipment Rack Layout
14.	DC-8 Integration Overview Dimensions for Mounting and Integration Fence
15.	AMMR 92 GHz Radiometer DC-8 Installation Details
16.	PSR Materials list PSR Fastener List

## Appendix C

### **PSR Drawing List**

A.J. Gasiewski  
January 25, 1996

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## **PSR2.DWG Layer Description**

**A.J. Gasiewski**  
**March 29, 1996**

**0: Main layer (empty). Required by Autocad.**

**1-7: Empty layers.**

**AIRFRAME:** Outline of the DC-8 airframe for illustration purposes.

**AXES:** Autocad lines used to designate special axes, for example, to generate bodies of revolution.

**AZENCODERGEARS:** Two gears on azimuthal shaft inside upper azimuthal drum for transferring angular position from the azimuthal shaft to the shaft of the azimuthal encoder.

**AZIMUTHASSEMBLY:** Upper and lower azimuthal drums and associated hardware comprising the housing for the azimuthal slip ring and azimuthal (upper) bearing.

**AZIMUTHBEARING:** 4" ID ring bearing for locating the upper end of the yoke vertical axis. This bearing normally supports less than 10% of the weight of the yoke and drum.

**AZIMUTHALMOTOR:** Azimuthal drive motor, including passive brake assembly.

**AZIMUTHALSHAFT:** Stainless steel drive shaft connecting azimuthal motor output shaft to yoke.

**BEAMENVELOPES:** Imaginary boundaries of radiometer antenna beams for viewing at several elevation angles.

**CALIBRATIONLOADS:** Hot and cold pyramidal calibration loads, located inside vertical support structure.

**CLEARANCECIRCLE:** Imaginary cylinder indicating clearance boundary outside of which all parts reside in order to avoid interference with the rotating yoke or drum.

**DEFPOINTS:** Defined points for Autocad location purposes.

**DIMENSIONSFRONT, DIMENSIONSSIDE, DIMENSIONSTOP:** Important overall dimensions to be used for PSR mounting and integration purposes.

**DRUM:** PSR scanhead drum containing radiometers, computers, digital correlators, and miscellaneous electronics (outline only shown). The drum is fabricated from rolled 2024 Al reinforced by rolled angle aluminum ribs and axial stiffeners. An inspection cover allows access to

the inside of the drum. The drum is sealed and purged with dry nitrogen; a 1/3 PSI check valve is used to limit internal drum pressure.

**DRUM\_INT:** Scanhead drum interior (empty layer). Drum interior details are documented in separate drawing files.

**ELEVBEARINGS:** 4" ID ring bearings that locate and support the scanhead drum.

**ELEVBRACKETS:** Aluminum brackets fastening the PSR drum to the main bearing inner flange plates. These brackets (2024 Al) contain the elevation bearings, and accommodate the entire weight and wind load of the drum.

**ELEVGEARS:** Small stainless steel drive gear and large stainless steel ring gear that drive the scanhead drum in elevation.

**ELEV MOTOR:** Elevation drive motor, including passive brake assembly.

**ELEV MOTOR MOUNTS:** Three mounts for elevation drive motor.

**ENCODERS:** 14-bit optical encoders providing absolute angular position feedback of the scanhead drum and yoke.

**ENDCAP-DRIVE:** Drive-side scanhead drum endcap. Turned 2024 Al.

**ENDCAP-IDLE:** Idle-side scanhead drum endcap. Turned 2024 Al.

**FACE:** Scanhead faceplate. This plate (0.1875 2024 Al) supports the radiometer feedhorns.

**FASTENERS:** Indicate location of bolts for structural yoke.

**FENCE:** Aircraft fence on DC-8 (for illustrative purposes only - not for fabrication purposes). The fence, designed by NASA/Servair, is intended to reduce the free-stream Q from ~550 to ~200 psf.

**HORIZPLATE:** Horizontal mounting plate. This plate supports the azimuthal assembly and calibration loads, and forms the upper portion of the vertical support structure. The plate is 0.250" thick 2024 Al. The plate can be made to form part of a pressure seal with minimal modification.

**LENS BOLTRINGS:** Bolt rings used to fasten the radiometer lens/feedhorn antennas to the scanhead faceplate.

**MAIN BEARING:** 30" ID main bearing used to accommodate 90% of the weight and loading of the drum and yoke.



**MAINBEARINGMOUNT:** Inner and outer race seats (2024 Al) for the 30" ID main ring bearing.

**OLDFENCES:** Old fence concepts.

**PRESSUREBOX:** DC-8 nadir-7 pressure box envelope (for fitting purposes only).

**SLIPRINGS:** Azimuthal and elevation electrical slip rings for providing transferring power and signals to the yoke and scanhead.

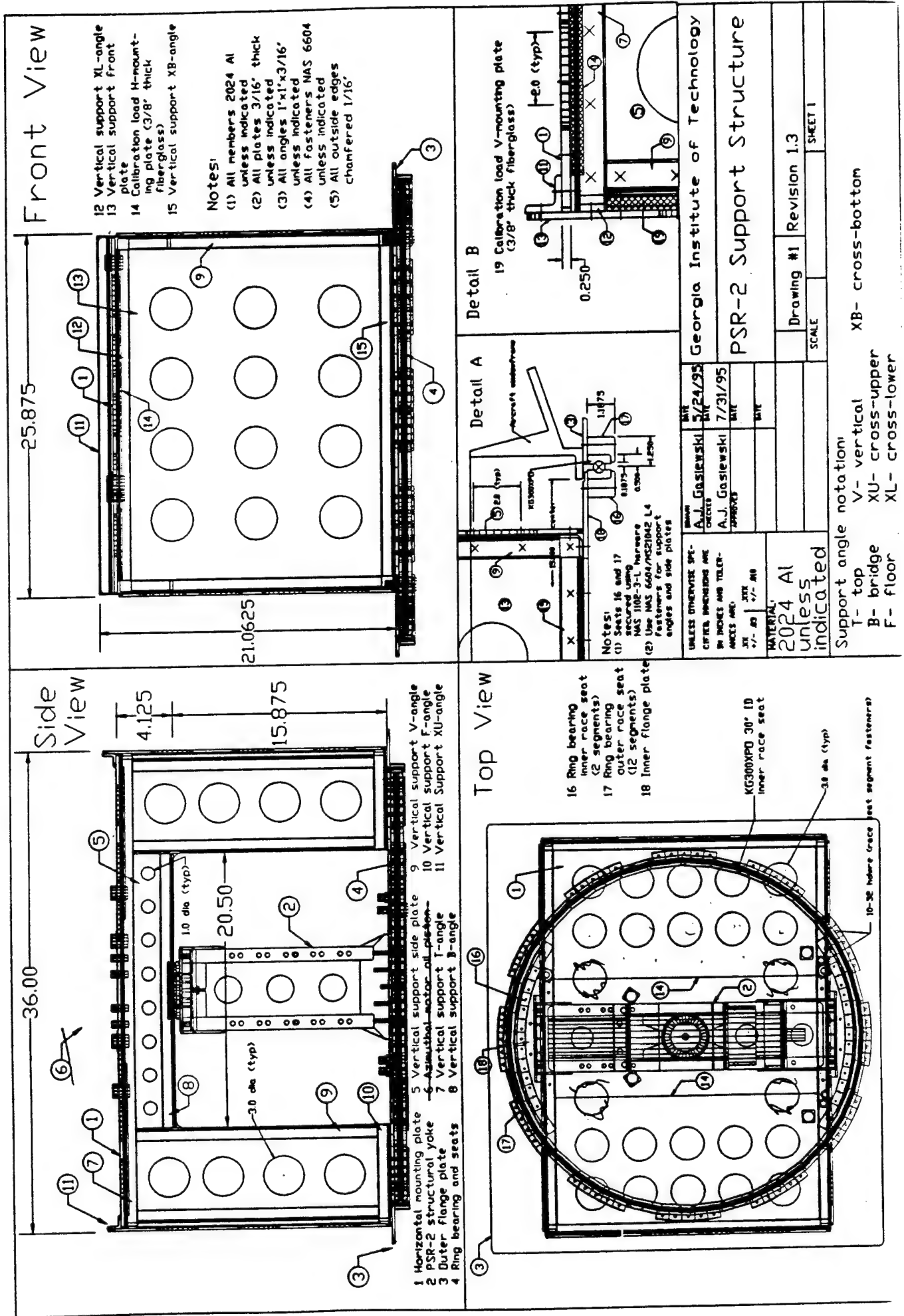
**TEMPLATES:** Autocad line templates used to generate bodies of revolution and other figures.

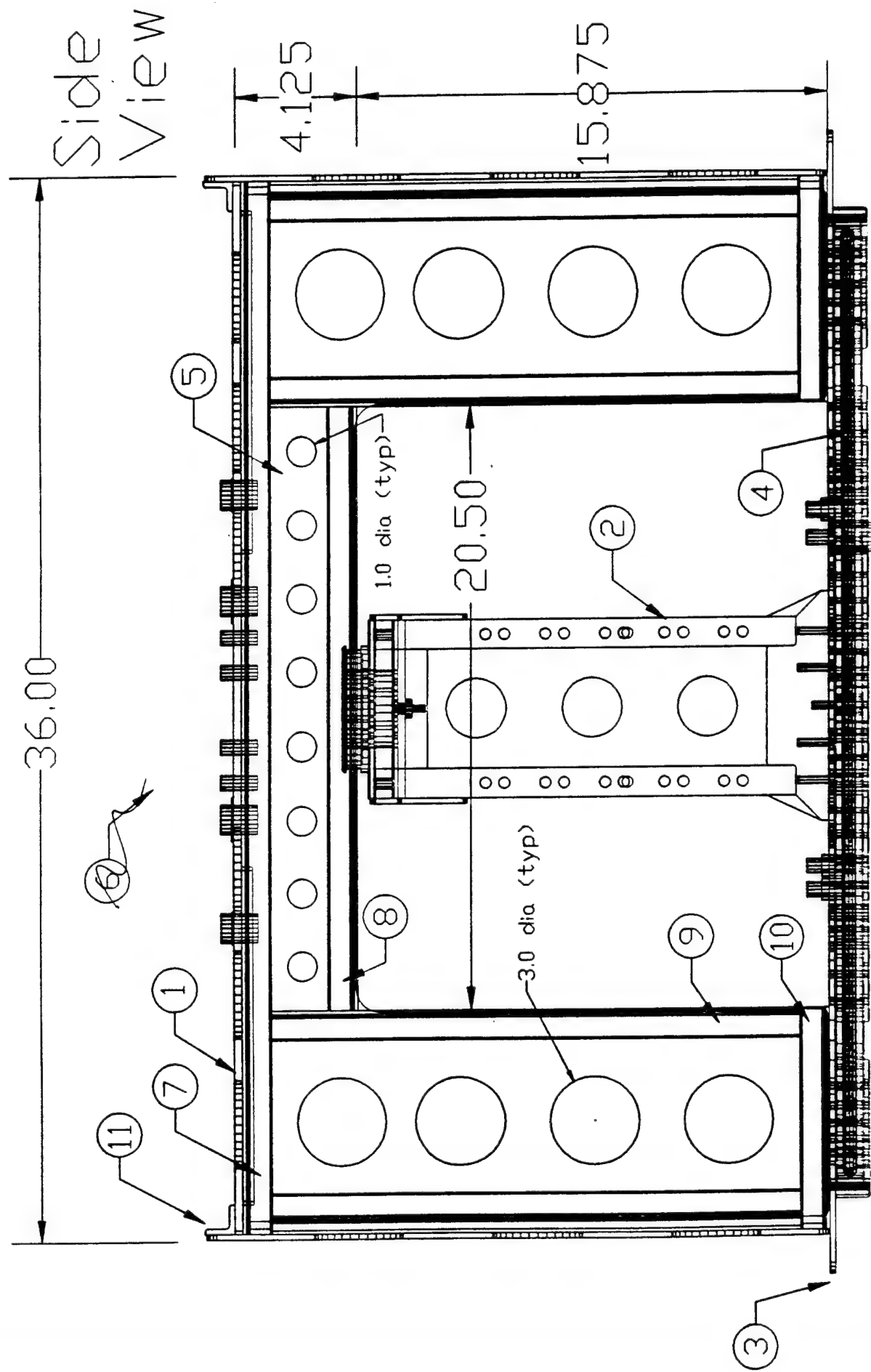
**TEMPSCAN:** Omega temperature measurement unit. This is a self-contained rack-mount sized unit mounted on top of the vertical support structure. The unit is supported by 3" tall standoffs, and itself measures 12" x 17" x 3".

**VERTSUPPORTS:** Vertical support structure used to locate the upper azimuthal assembly and support the calibration loads. The wall are fabricated from 3/16" 2024 Al plate and joined by 3/16" 6061 Al angle.

**WINDOWFRAME:** DC-8 nadir-7 window frame for illustrative and fitting purposes.

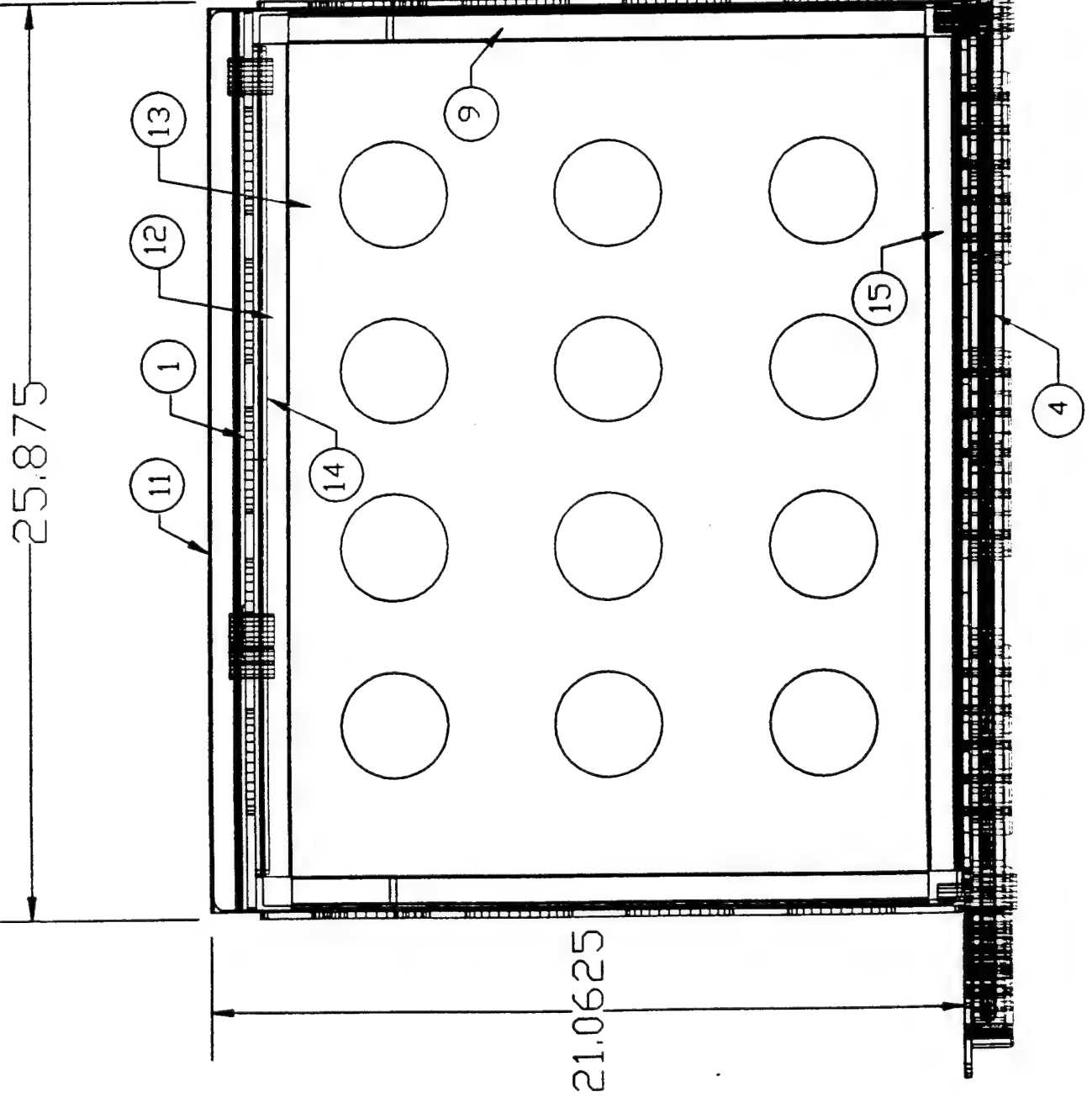
**YOKE:** Structural elements of the PSR yoke (2024 Al).





- |                             |                               |                              |
|-----------------------------|-------------------------------|------------------------------|
| 1 Horizontal mounting plate | 5 Vertical support side plate | 9 Vertical support V-angle   |
| 2 PSR-2 structural yoke     | 6 Azimuthal motor oil piston  | 10 Vertical support F-angle  |
| 3 Outer flange plate        | 7 Vertical support T-angle    | 11 Vertical Support XU-angle |
| 4 Ring bearing and seats    | 8 Vertical support B-angle    |                              |

# Front View

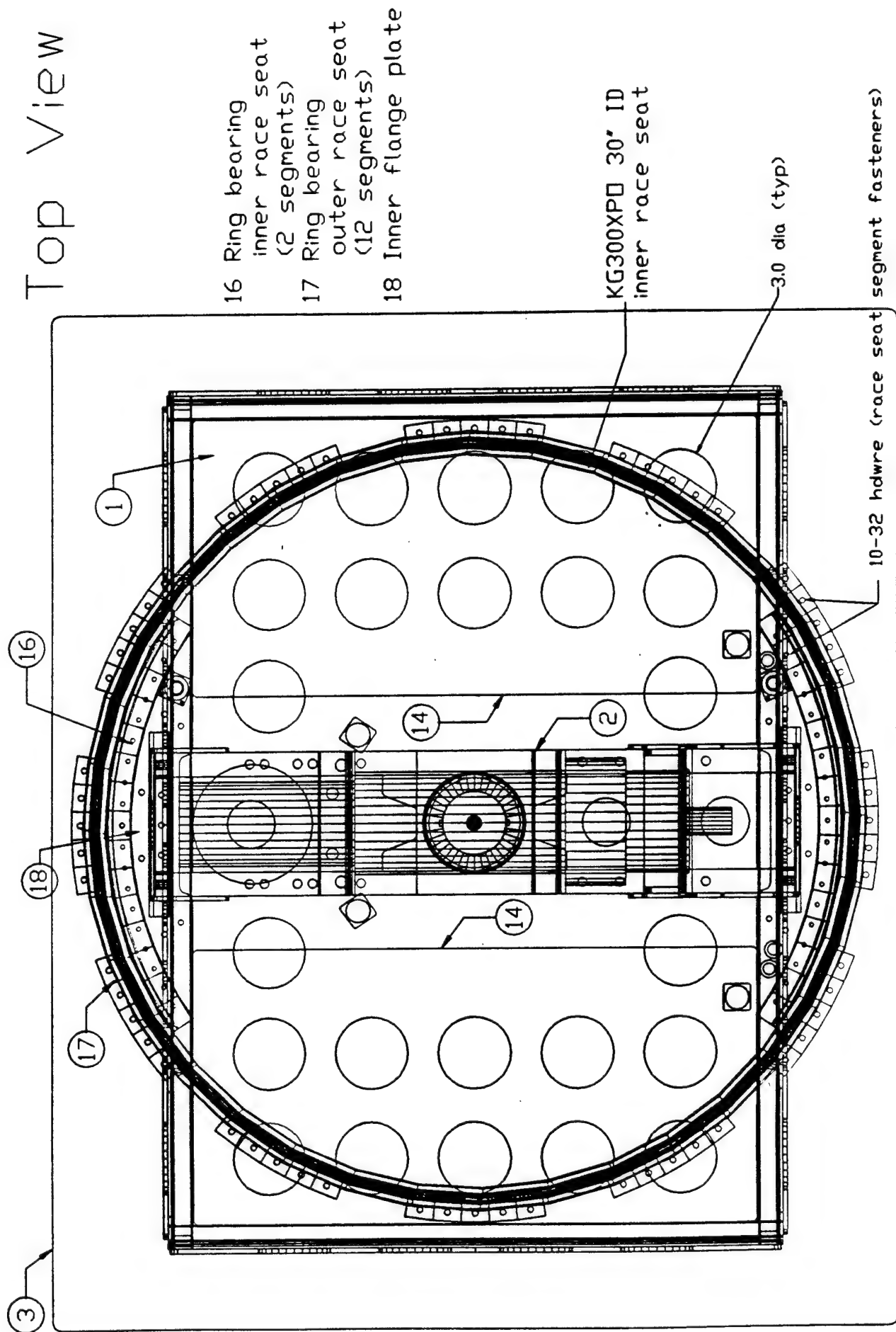


- 12 Vertical support XL-angle
- 13 Vertical support front plate
- 14 Calibration load H-mounting plate (3/8" thick fiberglass)
- 15 Vertical support XB-angle

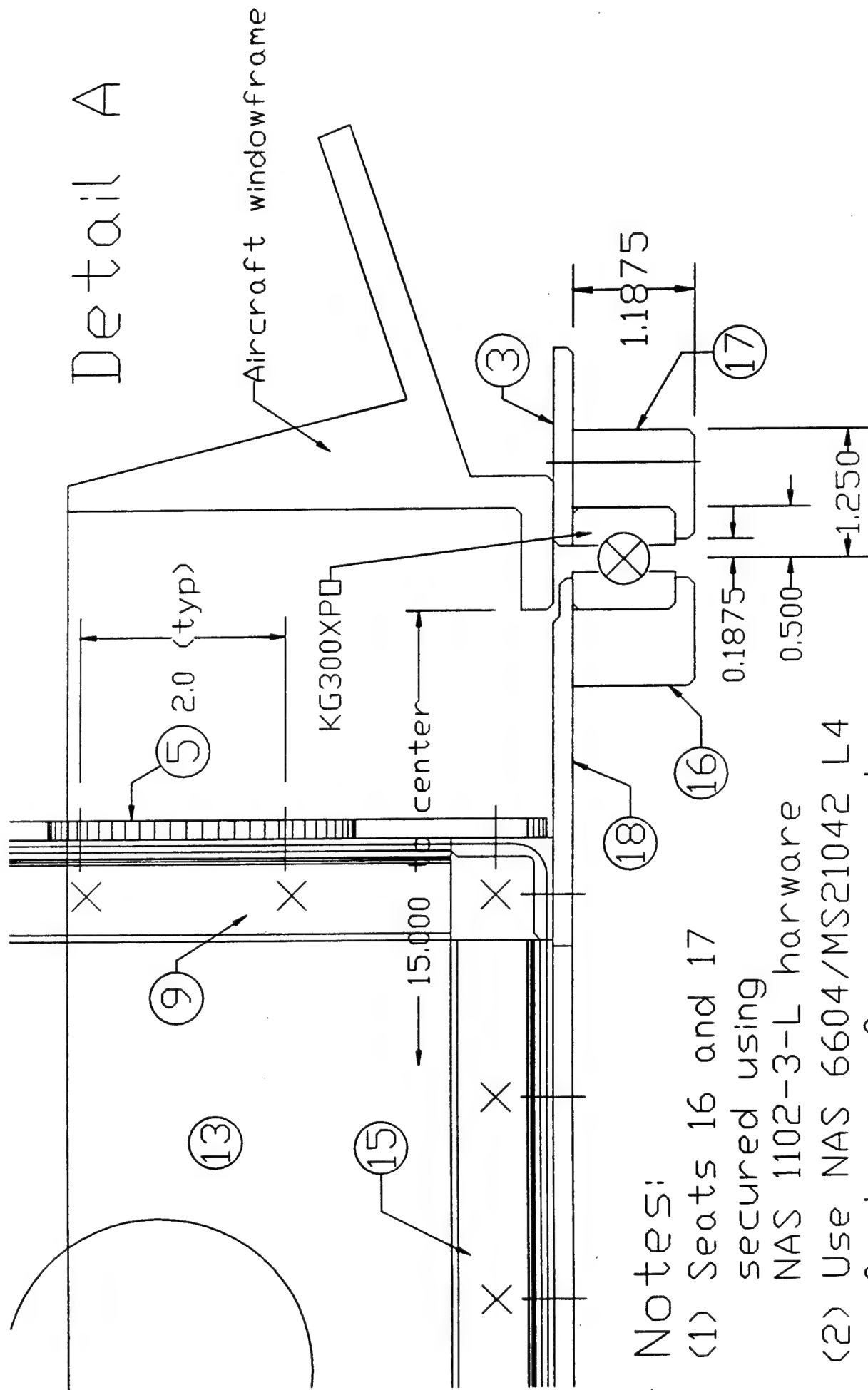
## Notes:

- (1) All members 2024 Al unless indicated
- (2) All plates 3/16" thick unless indicated
- (3) All angles 1"x1"x3/16" unless indicated
- (4) All fasteners NAS 6604 unless indicated
- (5) All outside edges chamfered 1/16"

# Top View



# Detail A

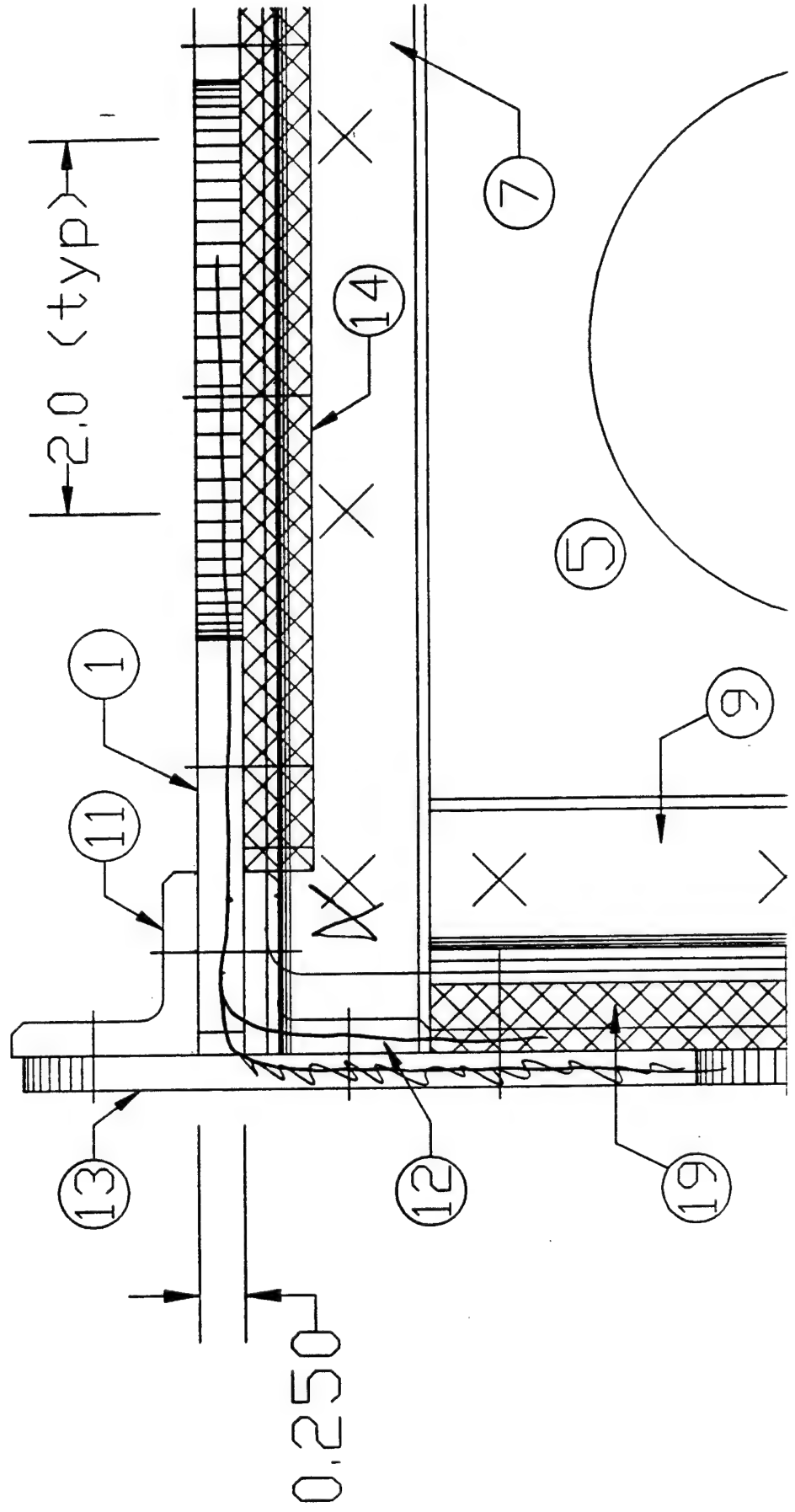


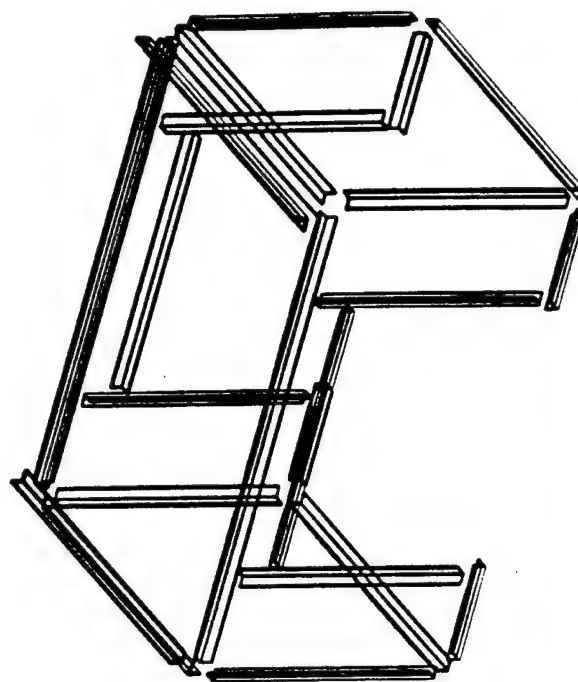
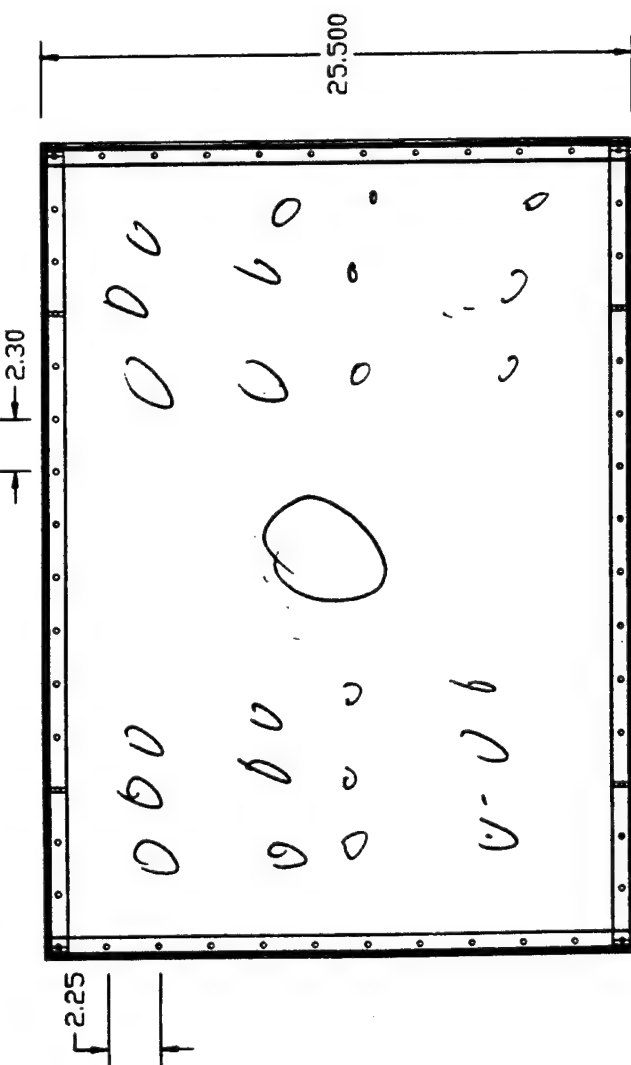
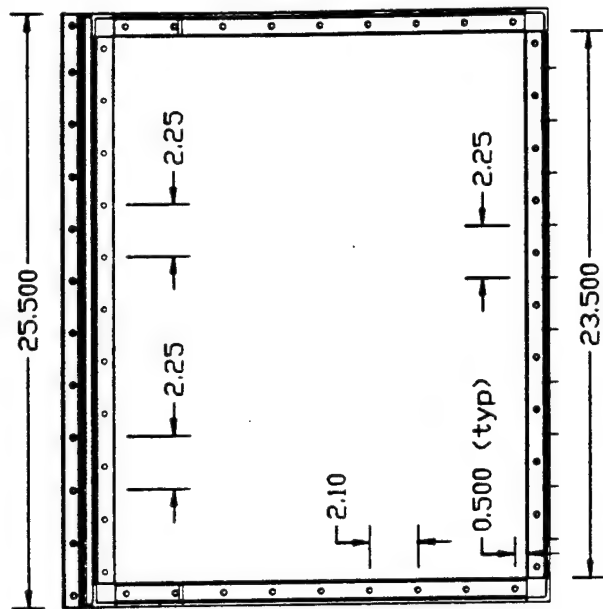
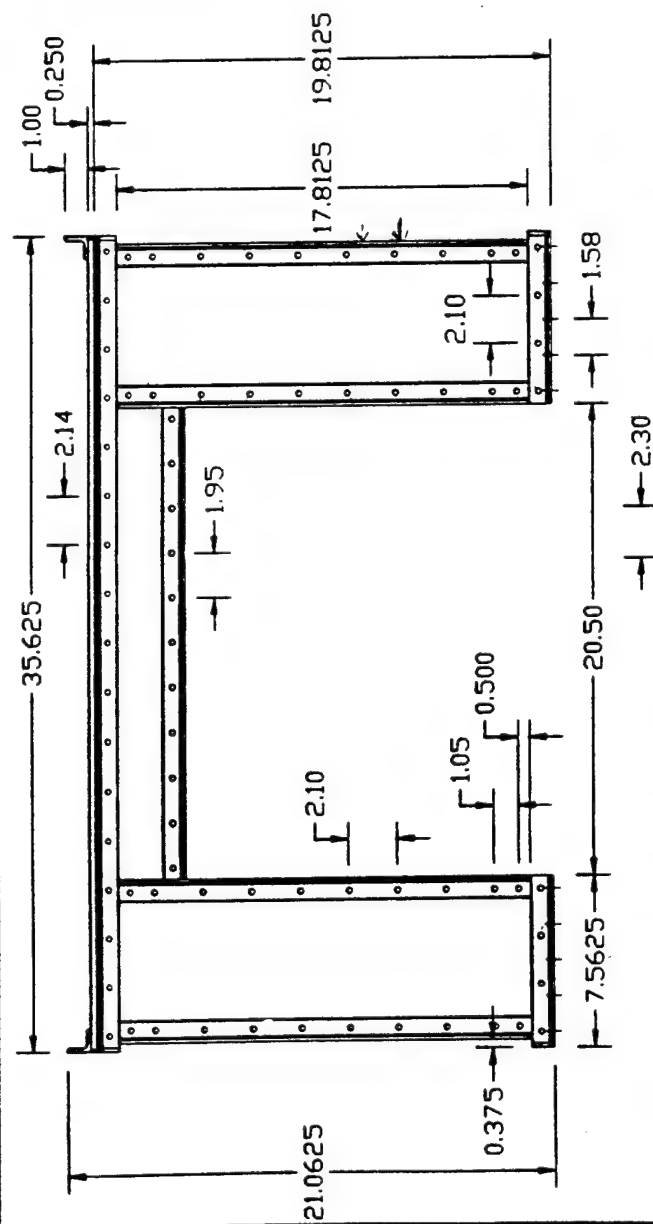
## Notes:

- (1) Seats 16 and 17 secured using NAS 1102-3-L hardware
- (2) Use NAS 6604/MS21042 L4 fasteners for support angles and side plates

# Detail B

19 Calibration load V-mounting plate  
(3/8" thick fiberglass)

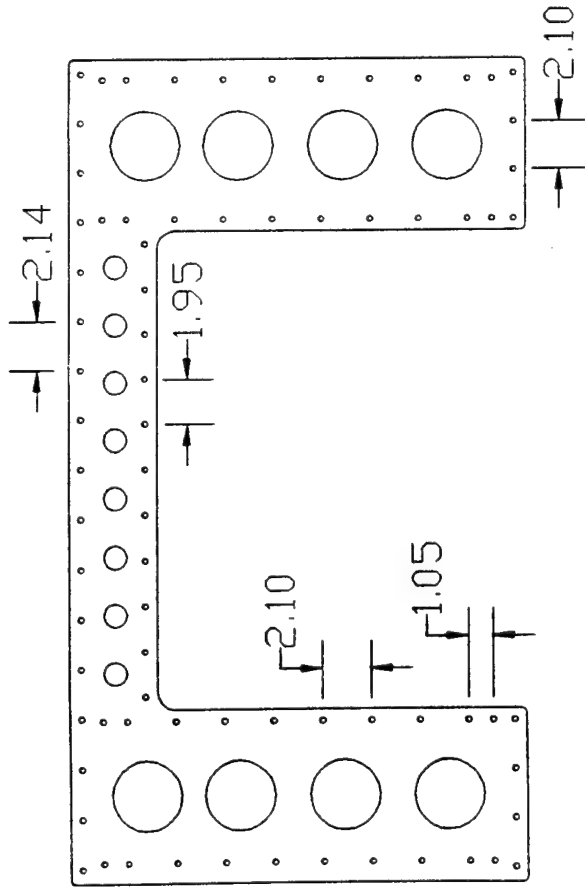




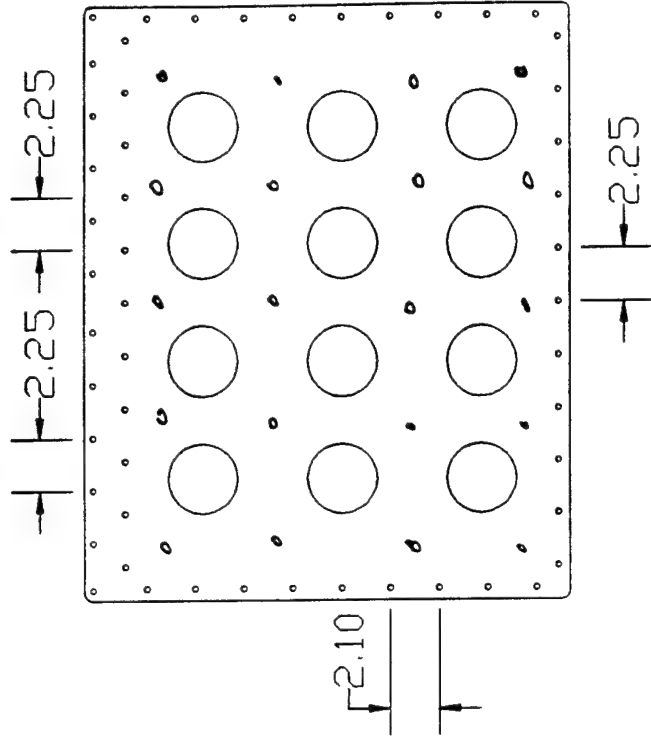
- Notes: (1) All angles 1x1x3/16 6061 Al  
(2) All fastener holes 1/4-28 clearance  
(3) All angles lengths +/- 0.010

[illegible]





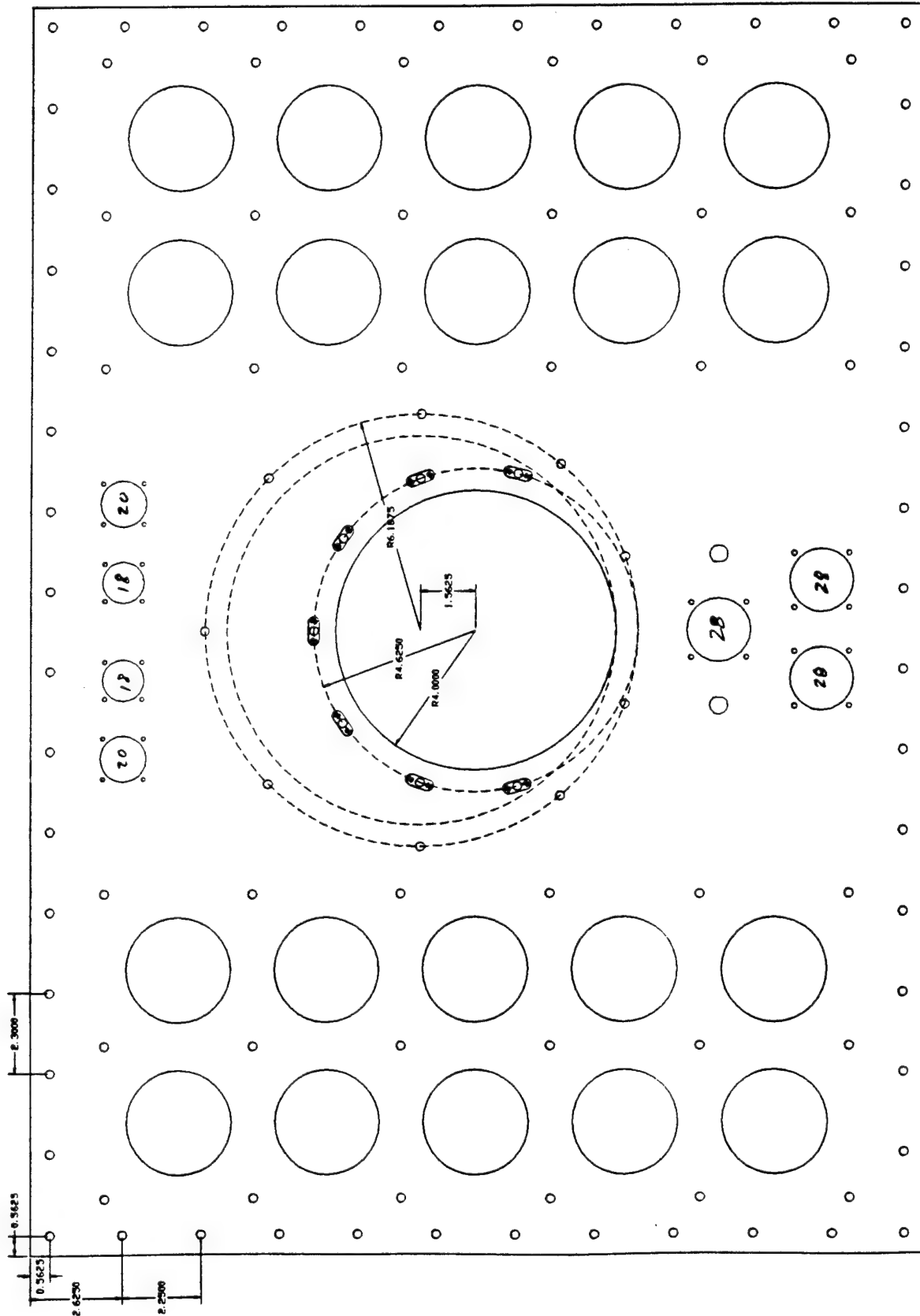
Side Plates (2 req'd)



Front/Back Plates (2 req'd)

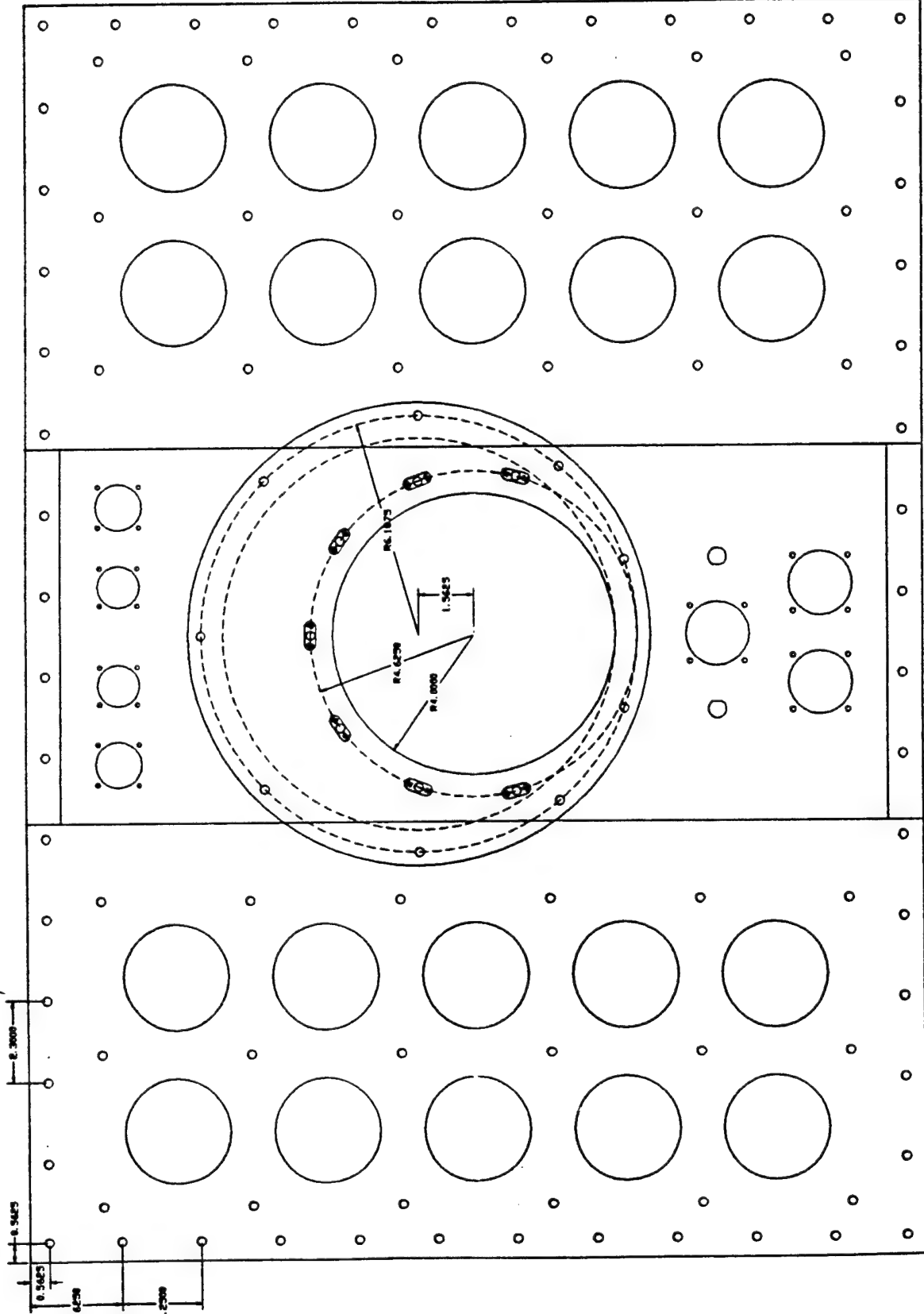
- Notes: (1) All plate 2024 T3 aluminum  
 (2) All fastener holes 1/4-28 clearance  
 (3) Chamfer outside vertical edges half thickness

DESIGNER: J. Gasinski	DATE: 7/19/95	Georgio Institute of Technology
CHECKED: J. Gasinski	DATE: 7/19/95	PSR-2 Support Structure
APPROVED: J. Gasinski	DATE: 7/19/95	Drawing M1
REVISION: 1	REVISION: 12	SHEET 3



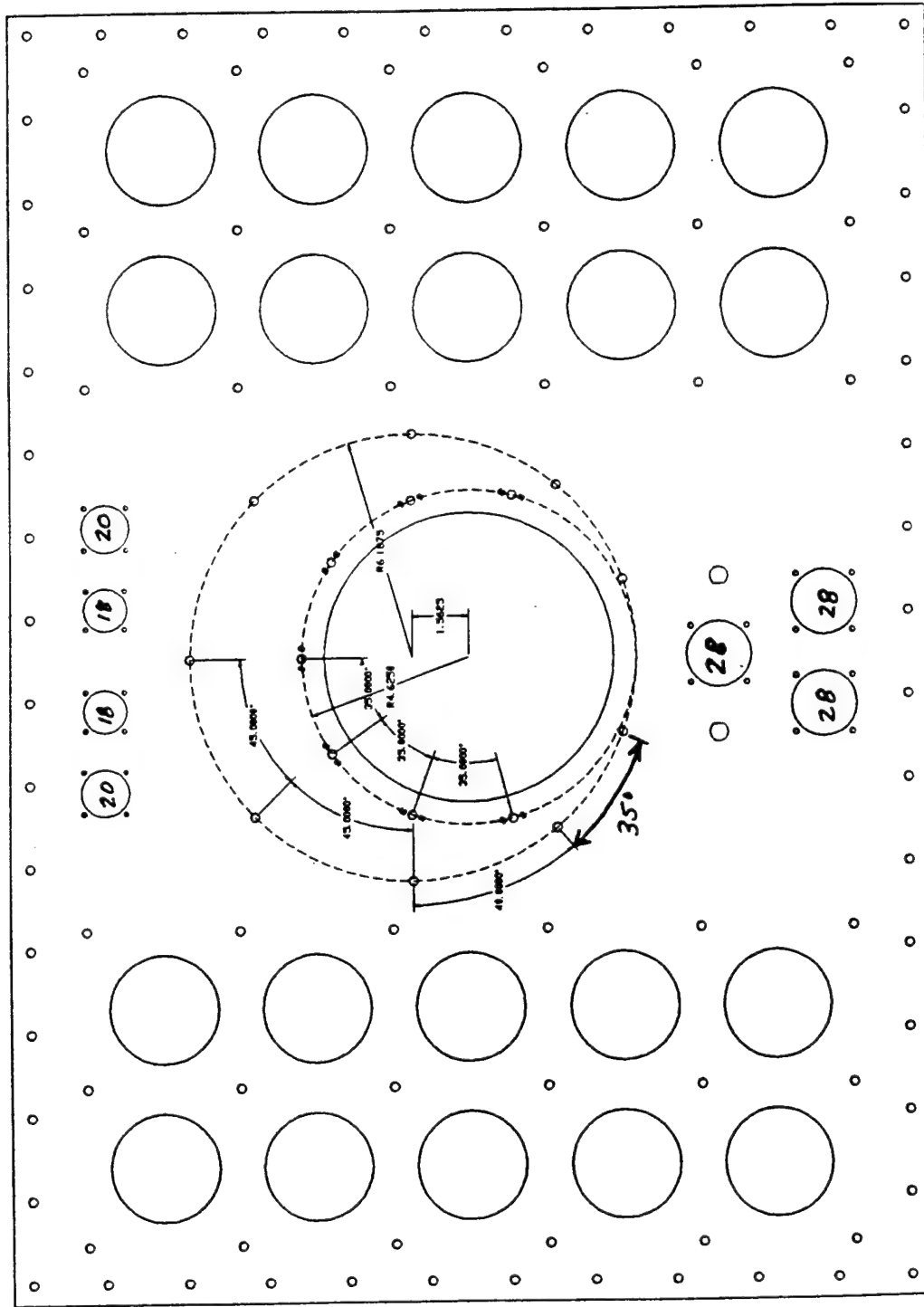
14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications.

UNIVERSITY OF GEORGIA CIVIL ENGINEERING DEPARTMENT 1000 UNIVERSITY AVENUE ATLANTA, GA 30302-0100 404/542-0300 WWW.UGA.EDU	DATE: 11/24/23 BY: [Signature] CHECKED: [Signature] APPROVED: [Signature]	Georgia Institute of Technology PSR-2 Horizontal Plate 1/4" 2024 M
--	--	--



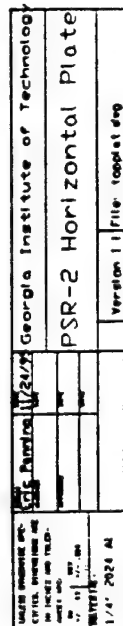
VALER PONTRE W- CIVIL ENGINEER AND ARCHITECT 12101 12th Ave N.W. ALBANY, AL 36850 1/4" 2024 A1	DATE: 1/24/24 BY: VALER PONTRE CHECKED: [blank] APPROVED: [blank]	PROJECT: PSR-2 Horizontal Plate SHEET: 1 OF 1	CLIENT: Georgia Institute of Technology
--	--	--	---

14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications

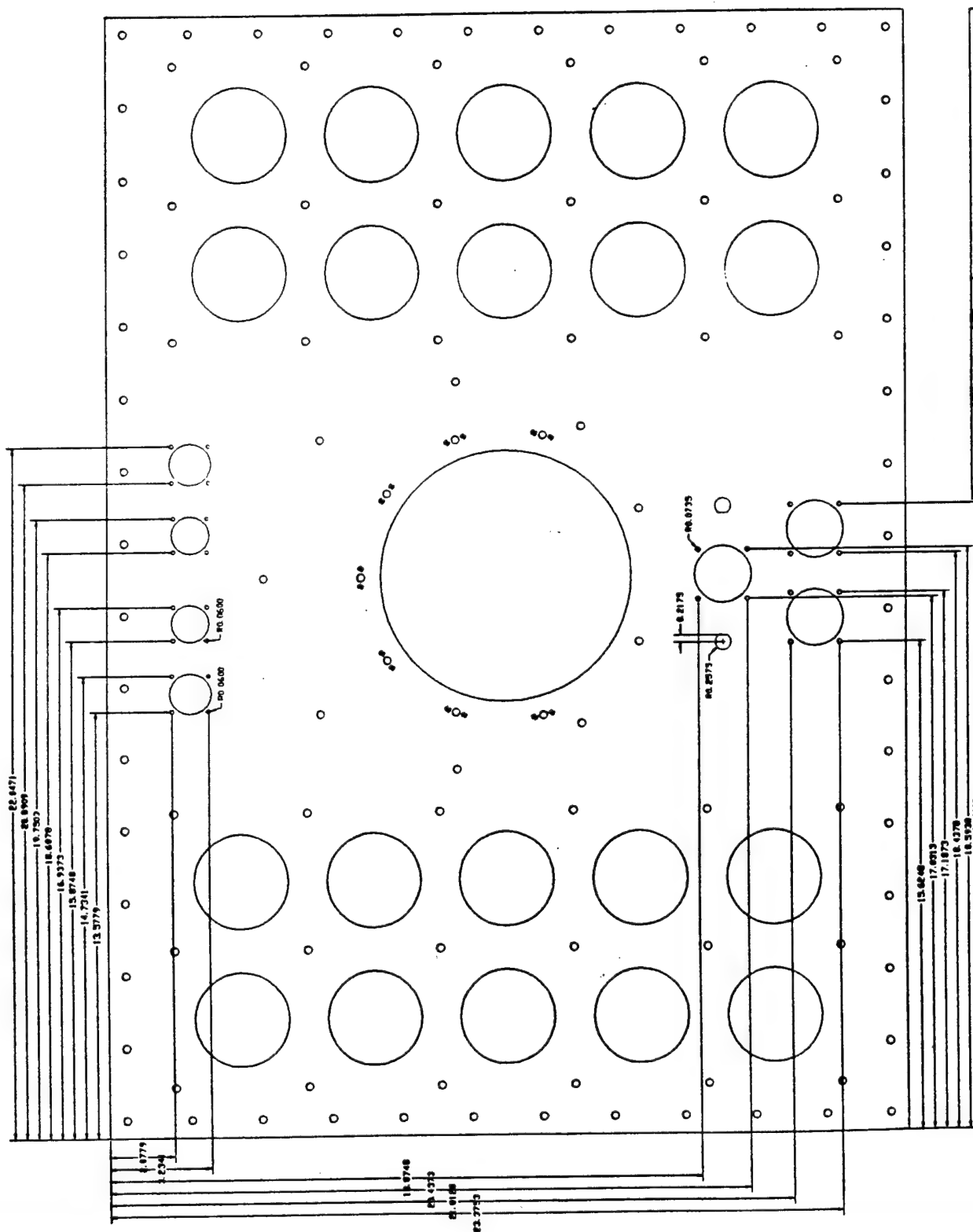


14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications.

DATE: 08/08/24	DESIGNED BY: [blank]	GEORGIA INSTITUTE OF TECHNOLOGY
DRAWN BY: [blank]	CHECKED BY: [blank]	PROJECT: PSR-2 Horizontal Plate
SCALE: 1/4" = 1"	FILE: top of dog	SHEET: [blank]

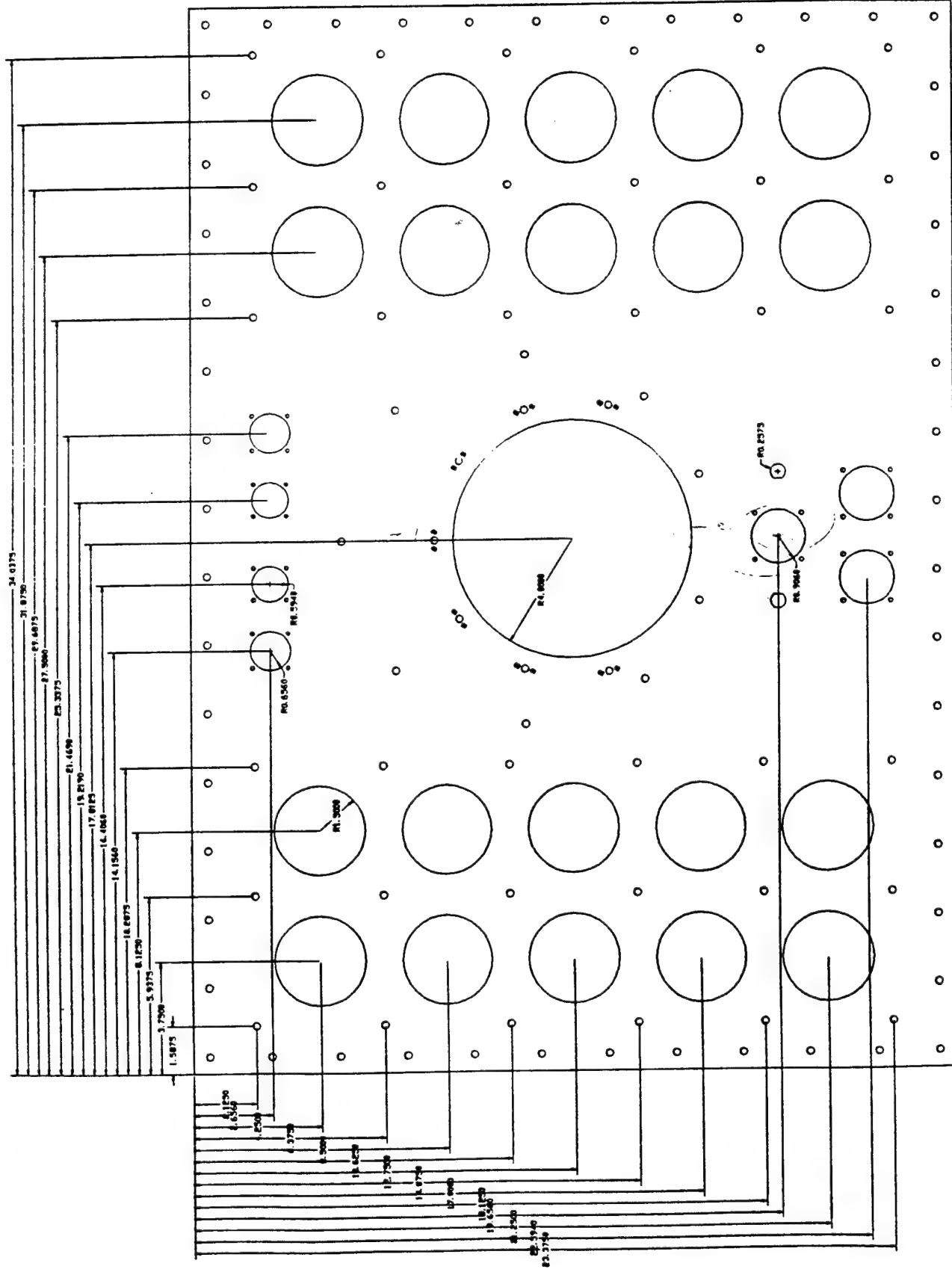


14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications.



14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications.

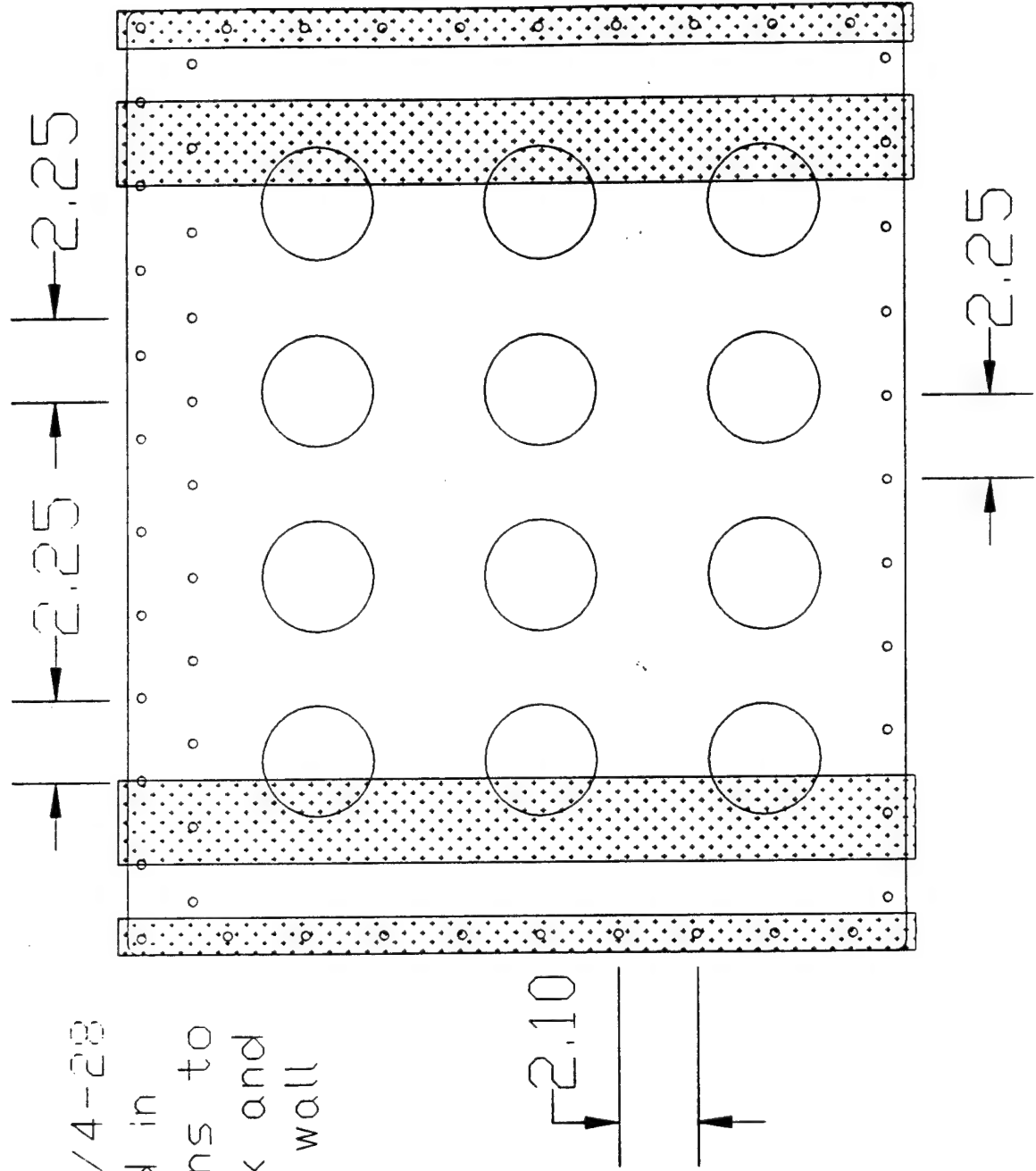
UNIVERSITY OF CALIFORNIA	DATE PRINTED: 01/24/25	Georgia Institute of Technology
1/4" x 2" x 1/4"	PSR-2 Horizontal Plate	
1/4" x 2" x 1/4"	File: toppling.dwg	



14 Rivets (MS20426BB3-7) and 7 nut plates, nut plates are on top side (shown) and rivets are countersunk from the backside. See attachment for rivet head specifications.

DATE: 1/4/2024	BY: [Signature]	PROJECT: PSR-2 Horizontal Plate
CHECKED: [Signature]	DATE: 1/4/2024	SCALE: 1/4" = 1"
FILE: top of sheet		

Countersunk 1/4-28  
bolts required in  
hatched regions to  
insure highlock and  
pressure box wall  
clearance.



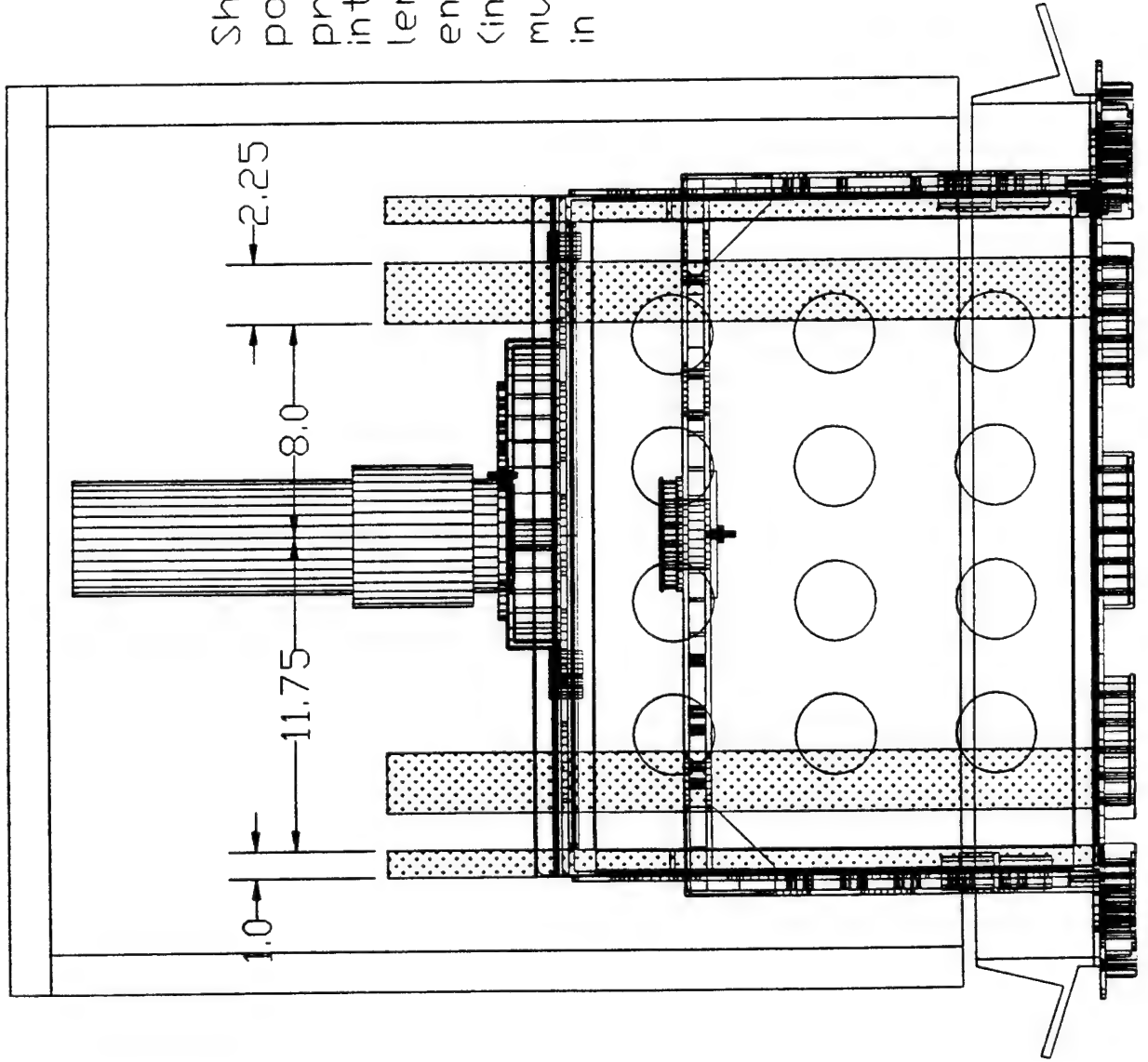
AJG 1/6/95

Front/Back Plates (2 req'd)



Shaded regions indicate potential highlock and pressure box corner interference. Maximum length of 36.0" from endplate-to-endplate (including boltheads) must not be exceeded in these regions.

AJG 1/6/96

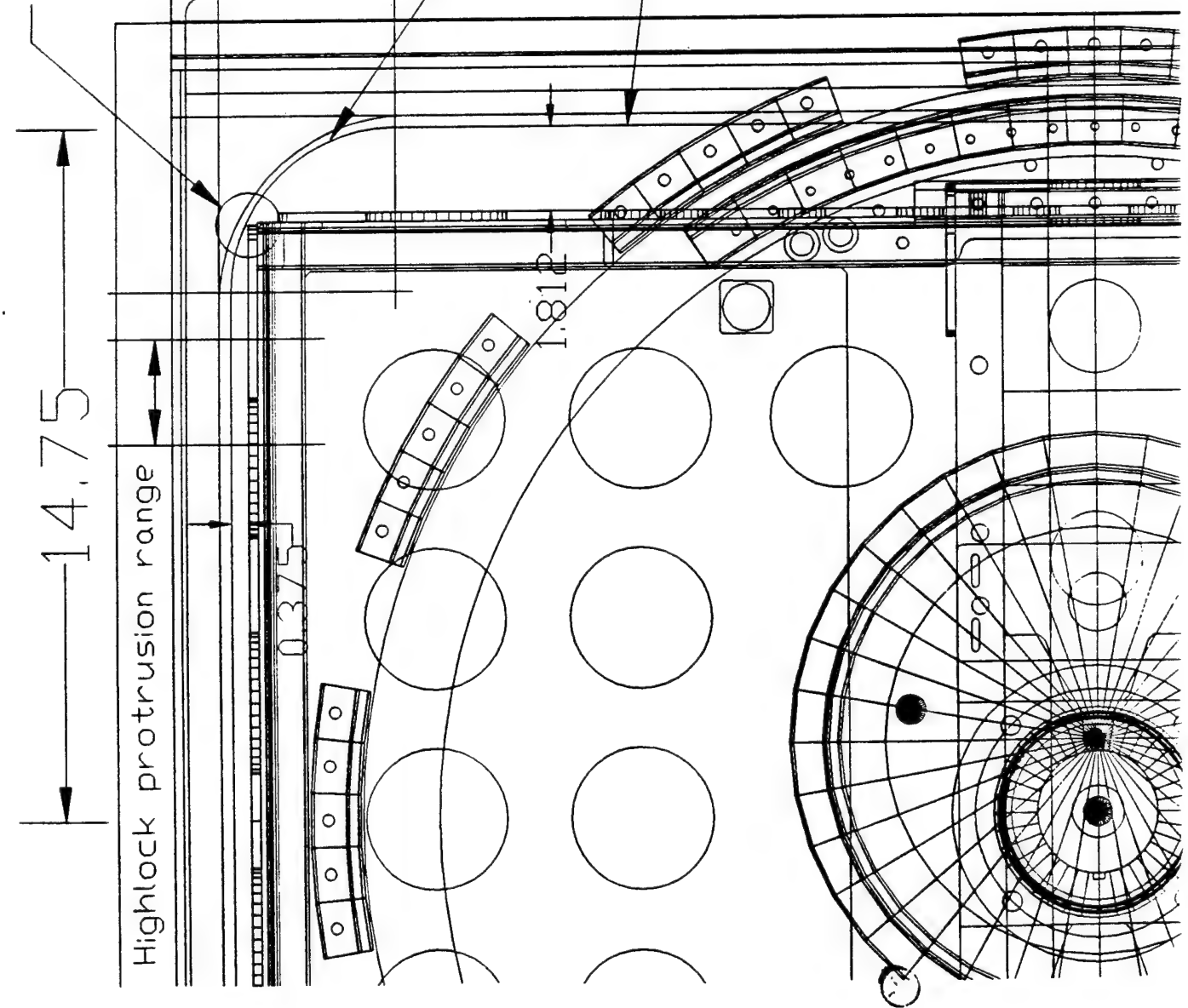


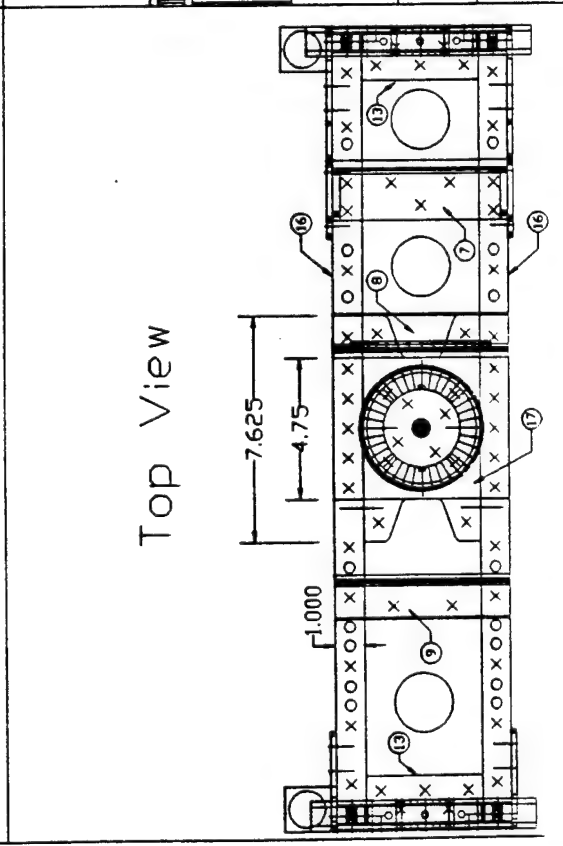
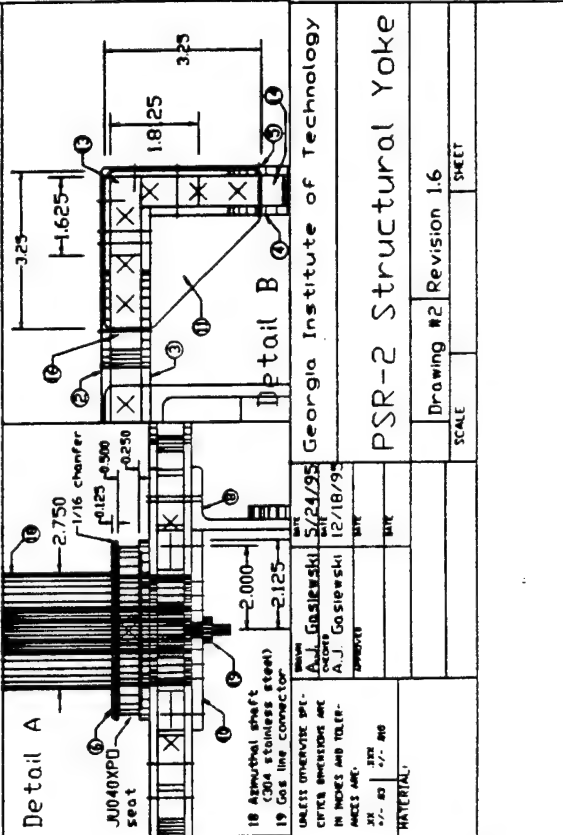
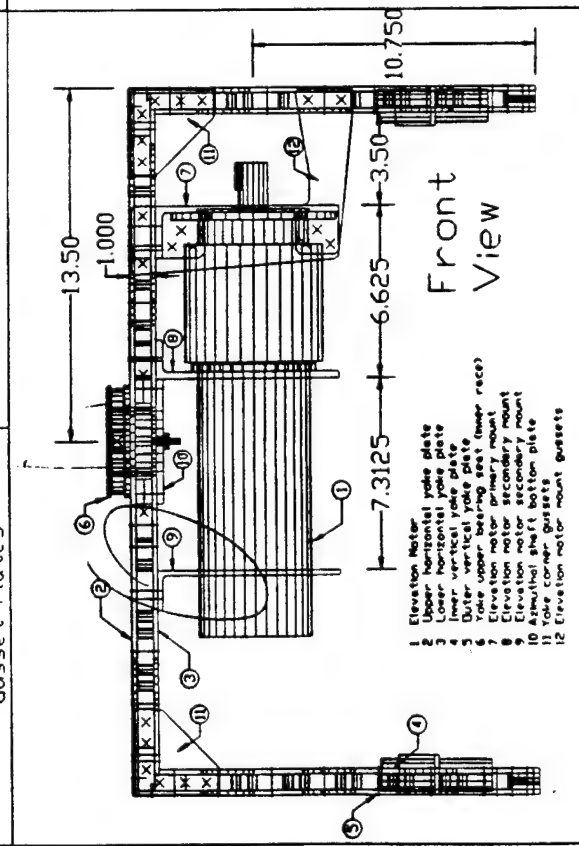
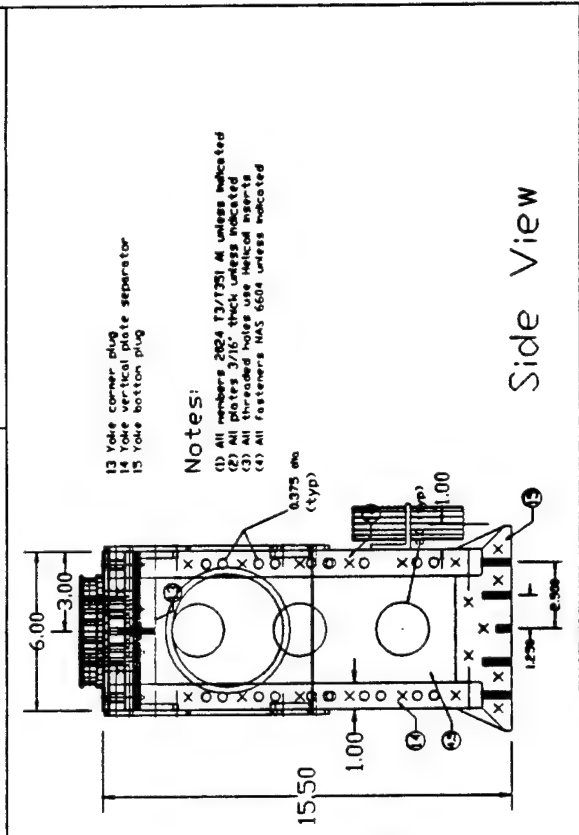
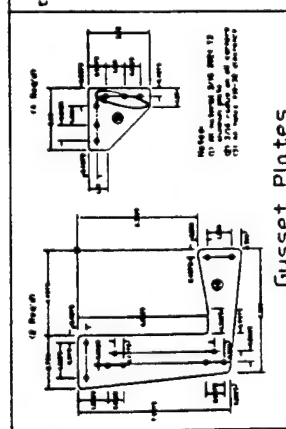
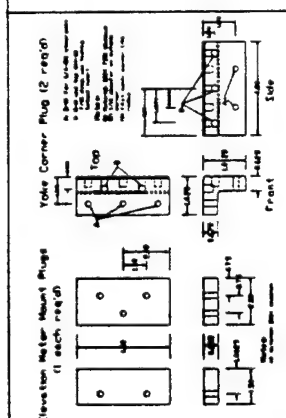
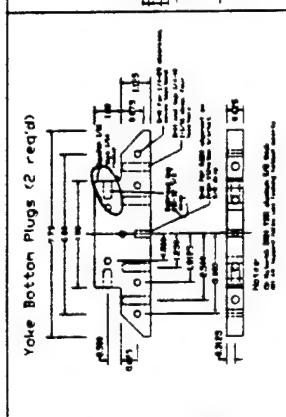
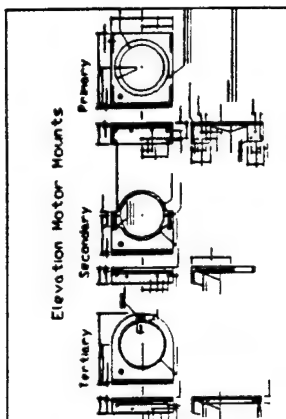
Corner of sideplate  
indicates region of  
potential interference.  
Corner must  
be chamfered  
w/30 deg edge  
to clear p-box  
and flat-head  
countersunk  
bolts needed  
on side plate  
vertical edges.

Pressure box  
inside envelope

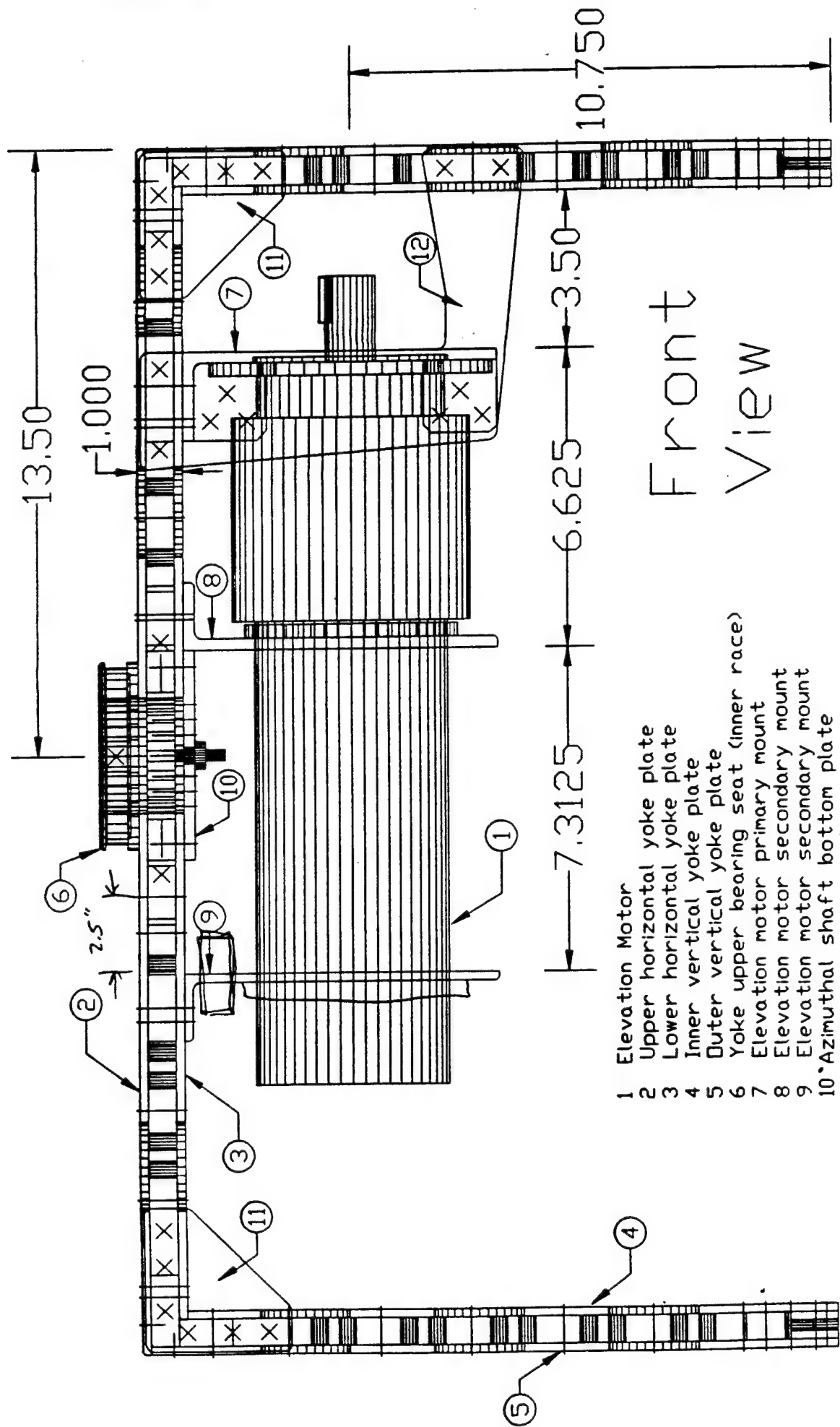
18.375

AJG 1/6/95

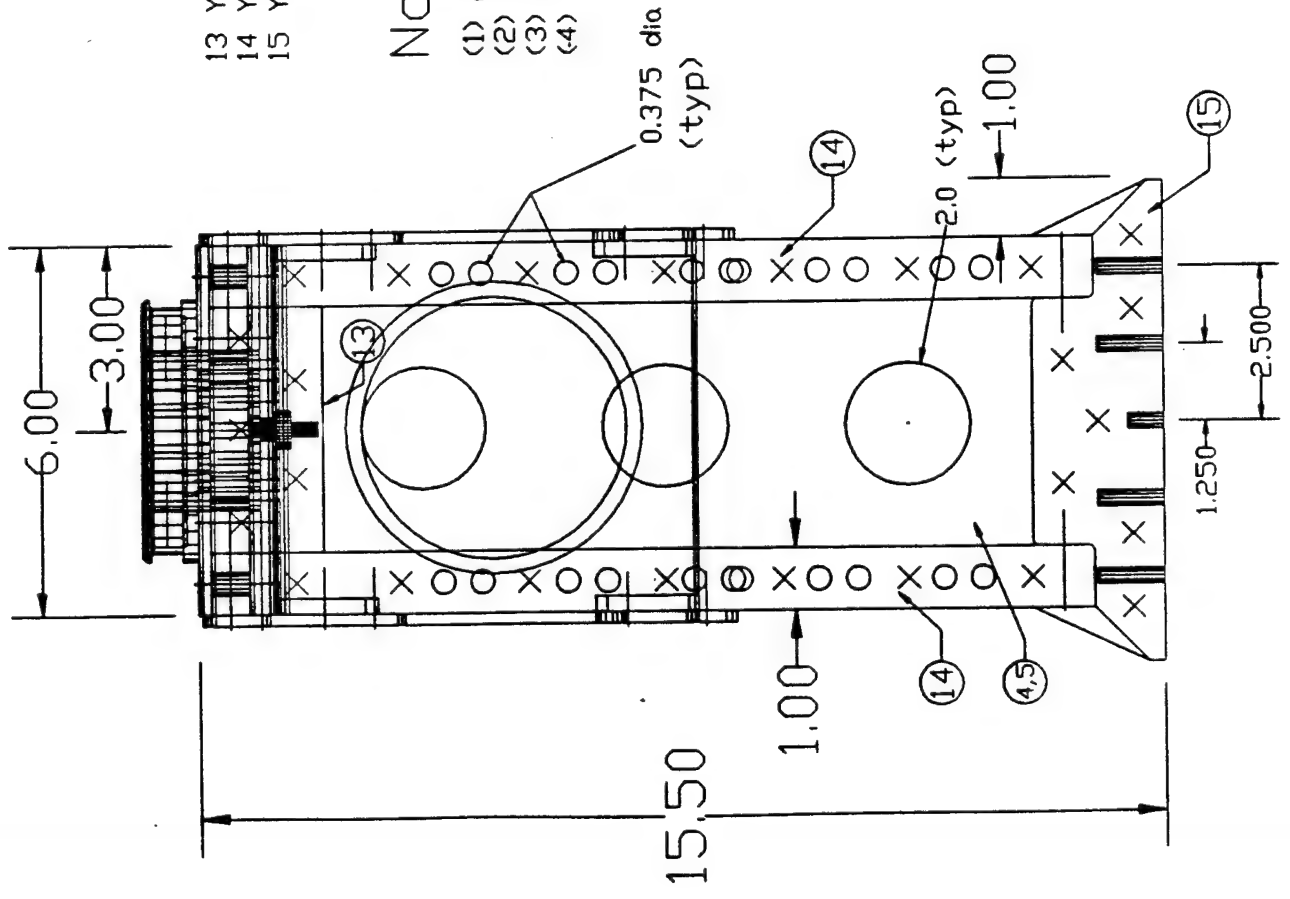




UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:	1/8" .003 3/16" .005 1/2" .010 3/4" .015 1" .020 1 1/2" .030 2" .040 3" .060 4" .080 6" .120 8" .150 10" .180 12" .240	DRAWN A. J. GASIEWSKI	DATE 5/24/95	Georgia Institute of Technology		
		CHECKED A. J. GASIEWSKI	DATE 12/18/95	PSR-2 Structural Yoke		
		DESIGNED GASIEWSKI	DATE	Drawing #2 Revision 1.6		
		MATERIAL	DATE	SCALE	SHEET	



- 1 Elevation Motor
- 2 Upper horizontal yoke plate
- 3 Lower horizontal yoke plate
- 4 Inner vertical yoke plate
- 5 Outer vertical yoke plate
- 6 Yoke upper bearing seat (inner race)
- 7 Elevation motor primary mount
- 8 Elevation motor secondary mount
- 9 Elevation motor secondary mount
- 10 Azimuthal shaft bottom plate
- 11 Yoke corner gussets
- 12 Elevation motor mount gaskets



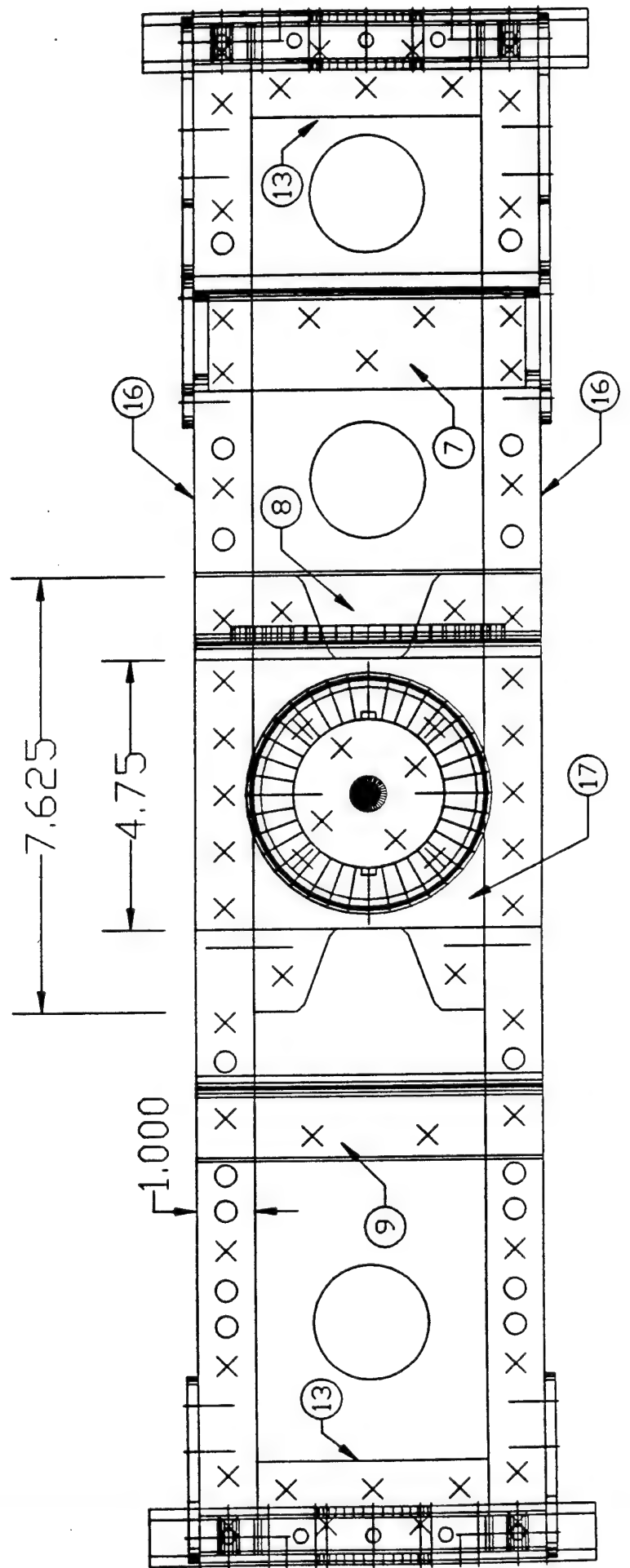
- 13 Yoke corner plug
- 14 Yoke vertical plate separator
- 15 Yoke bottom plug

### Notes:

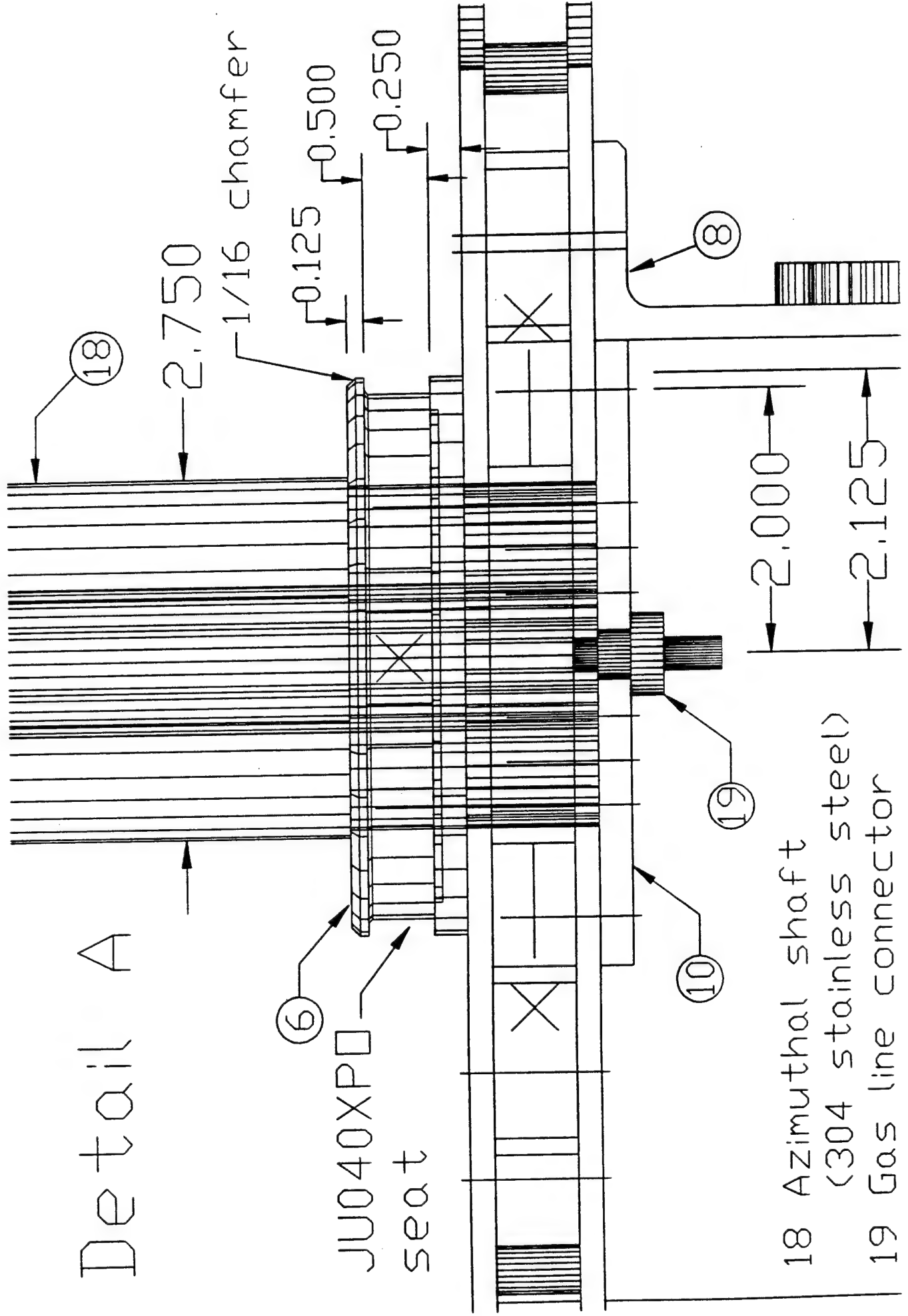
- (1) All members 2024 T3/T351 Al unless indicated
- (2) All plates 3/16" thick unless indicated
- (3) All threaded holes use Helicoil inserts
- (4) All fasteners NAS 6604 unless indicated

Side View

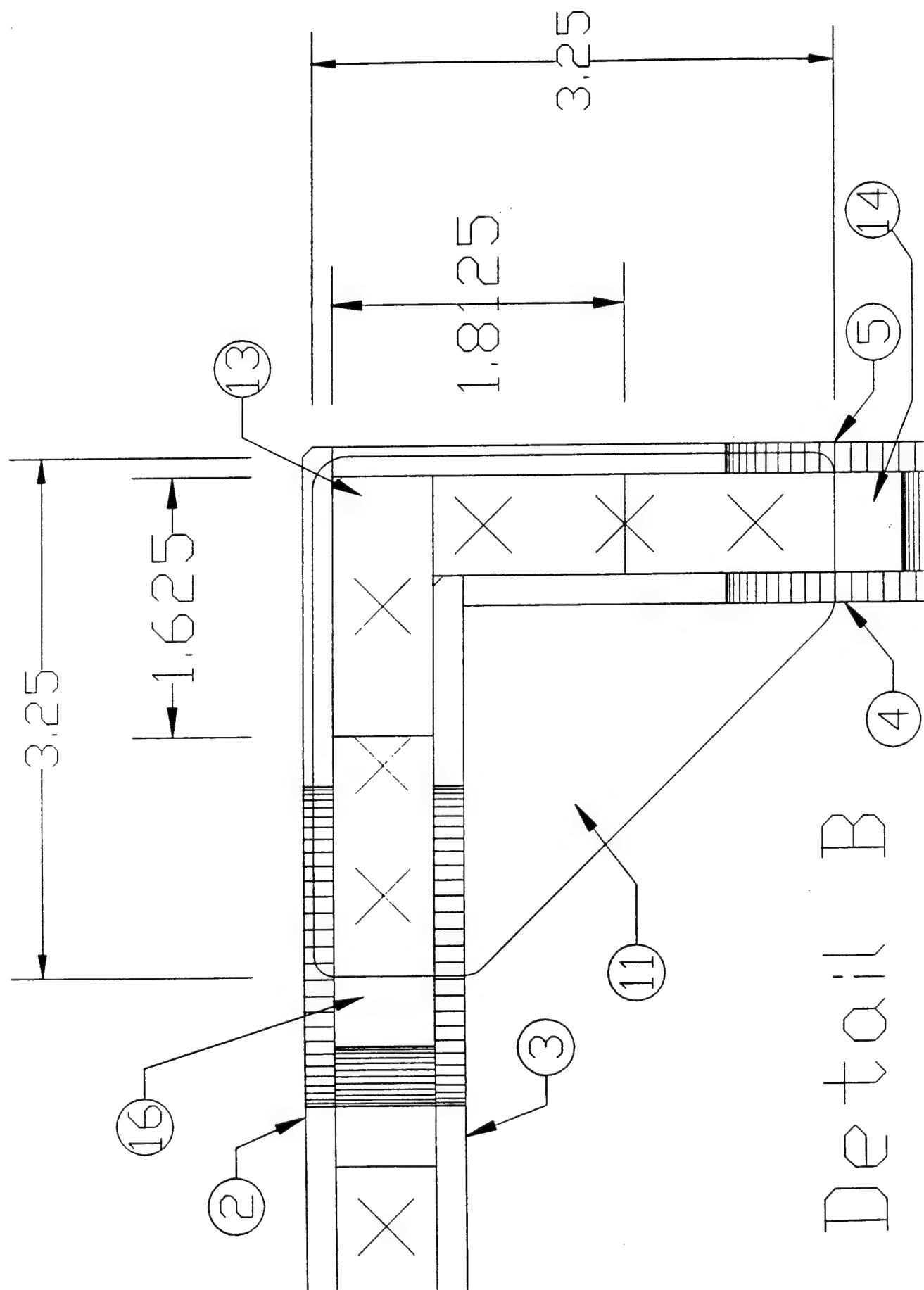
# Top View



# Detail A



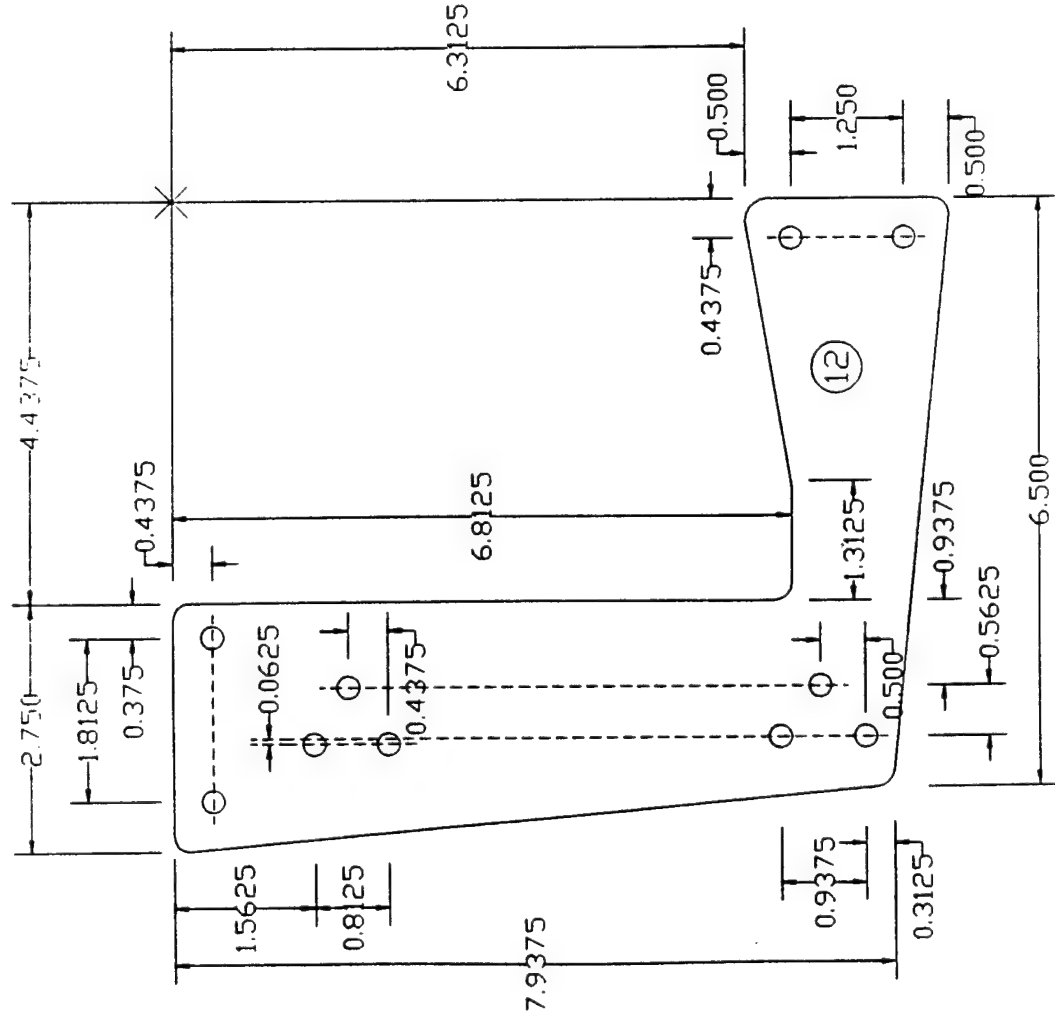
- 18 Azimuthal shaft  
(304 stainless steel)
- 19 Gas line connector



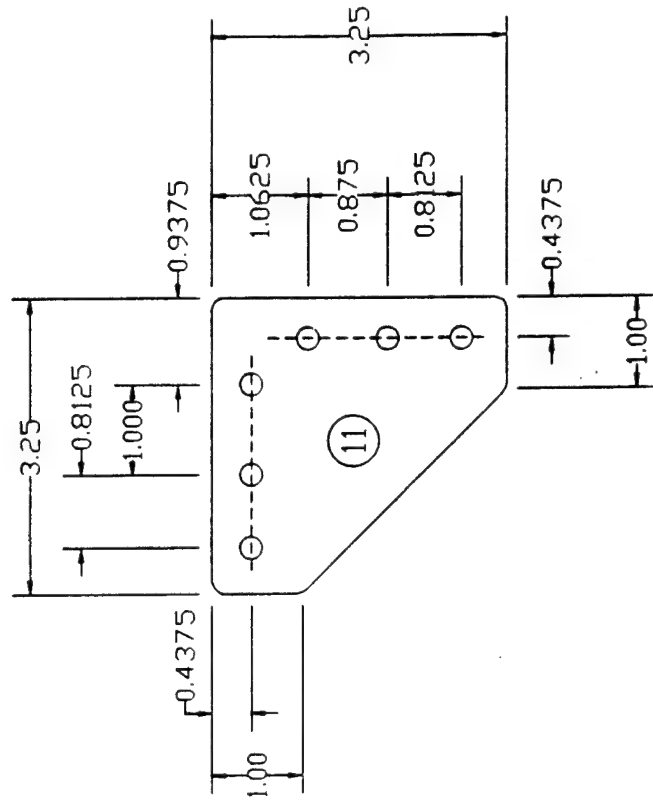
Detail B



(2 Req'd)



(4 Req'd)

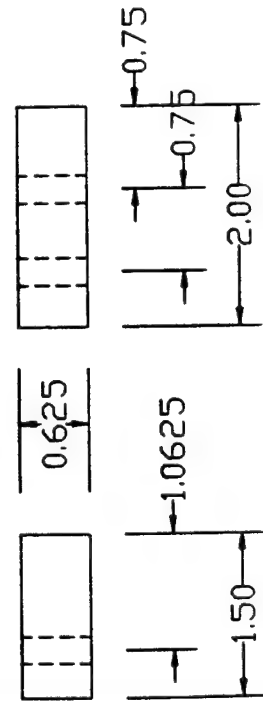
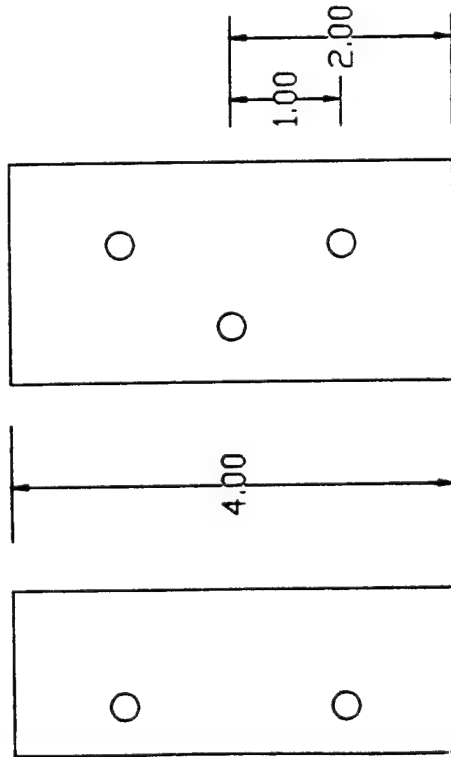


Notes:

- (1) All material 3/16 2024 T3 aluminum plate
- (2) 3/16 radius on all corners
- (3) All holes #10-32 clearance

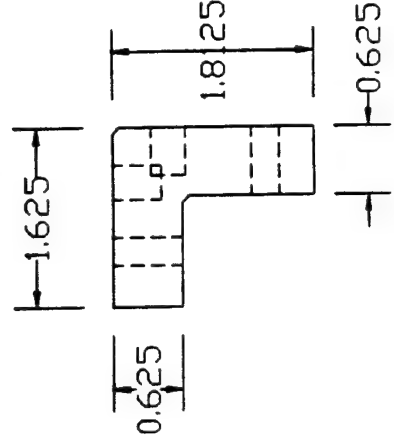
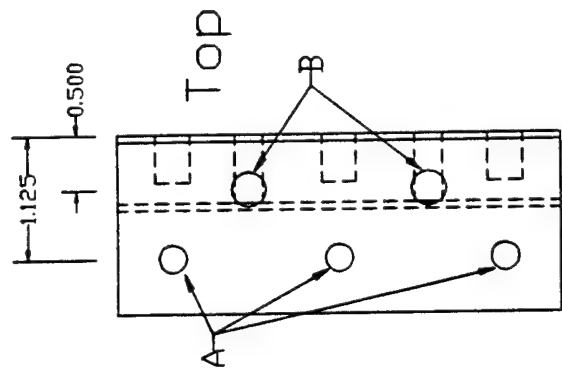
Gusset Plates

# Elevation Motor Mount Plugs (1 each req'd)

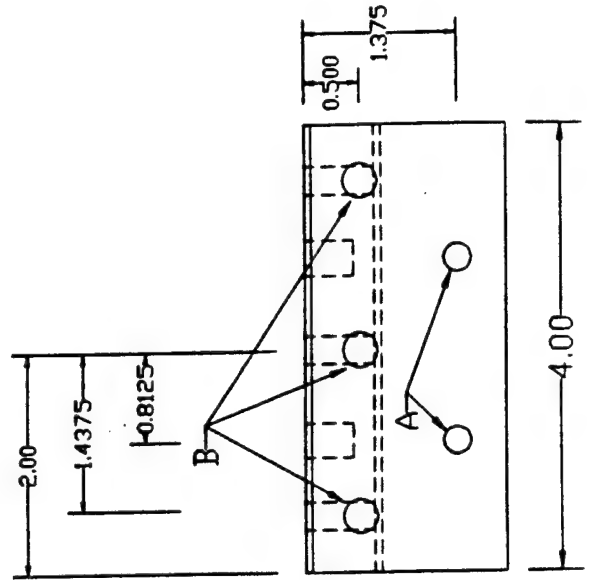


Notes:  
(1) Material: 2024 aluminum

# Yoke Corner Plug (2 req'd)

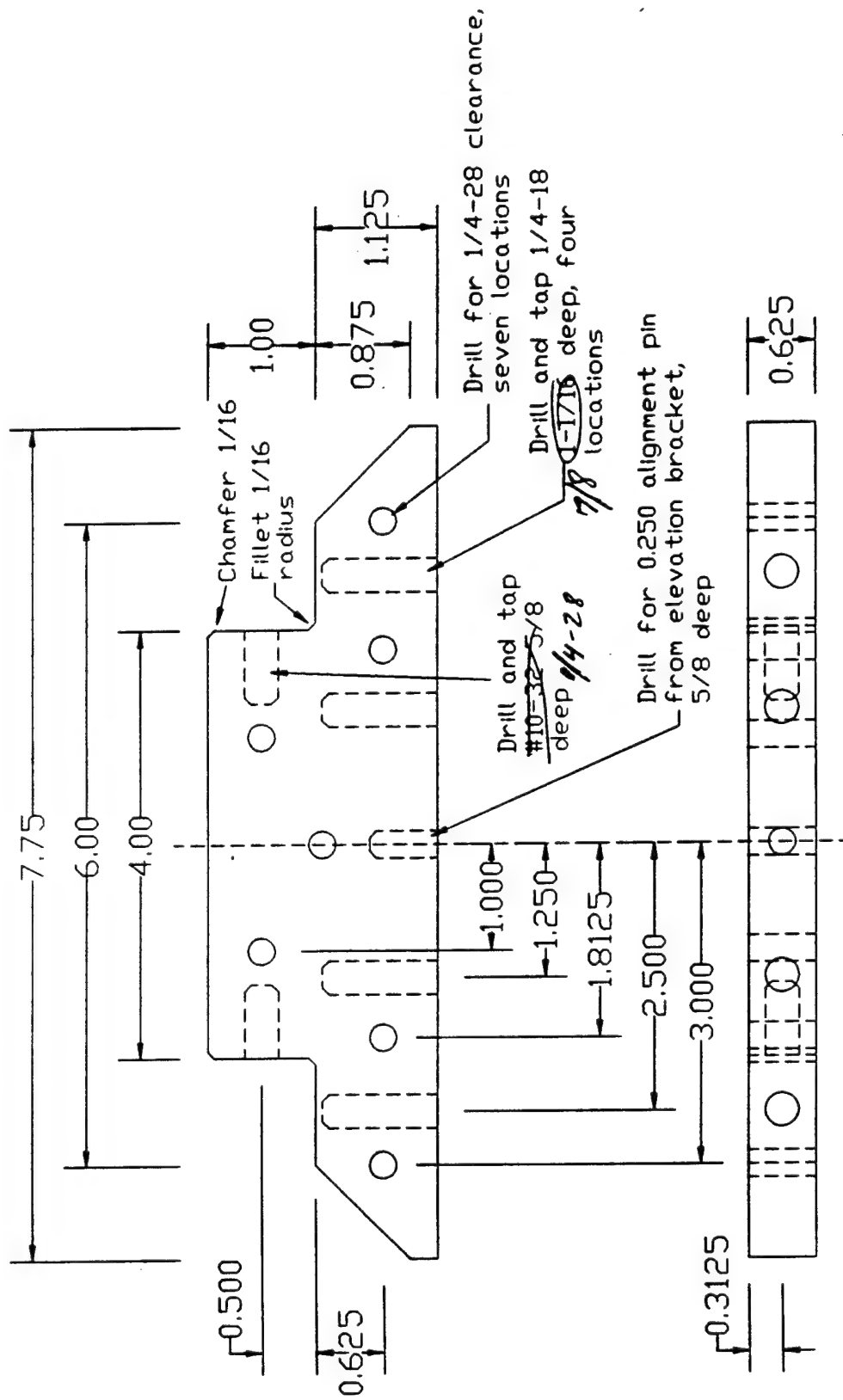


- A: Drill for 1/4-28 clearance  
B: Drill and tap #10-32  
7/16 deep, use locking  
helicoil insert
- Notes:  
(1) Material: 2024 T351 aluminum  
(2) 1/16 chamfer on outside  
corner  
(3) Fillet inside corner 1/16  
radius



Side

# Yoke Bottom Plugs (2 req'd)



## Notes:

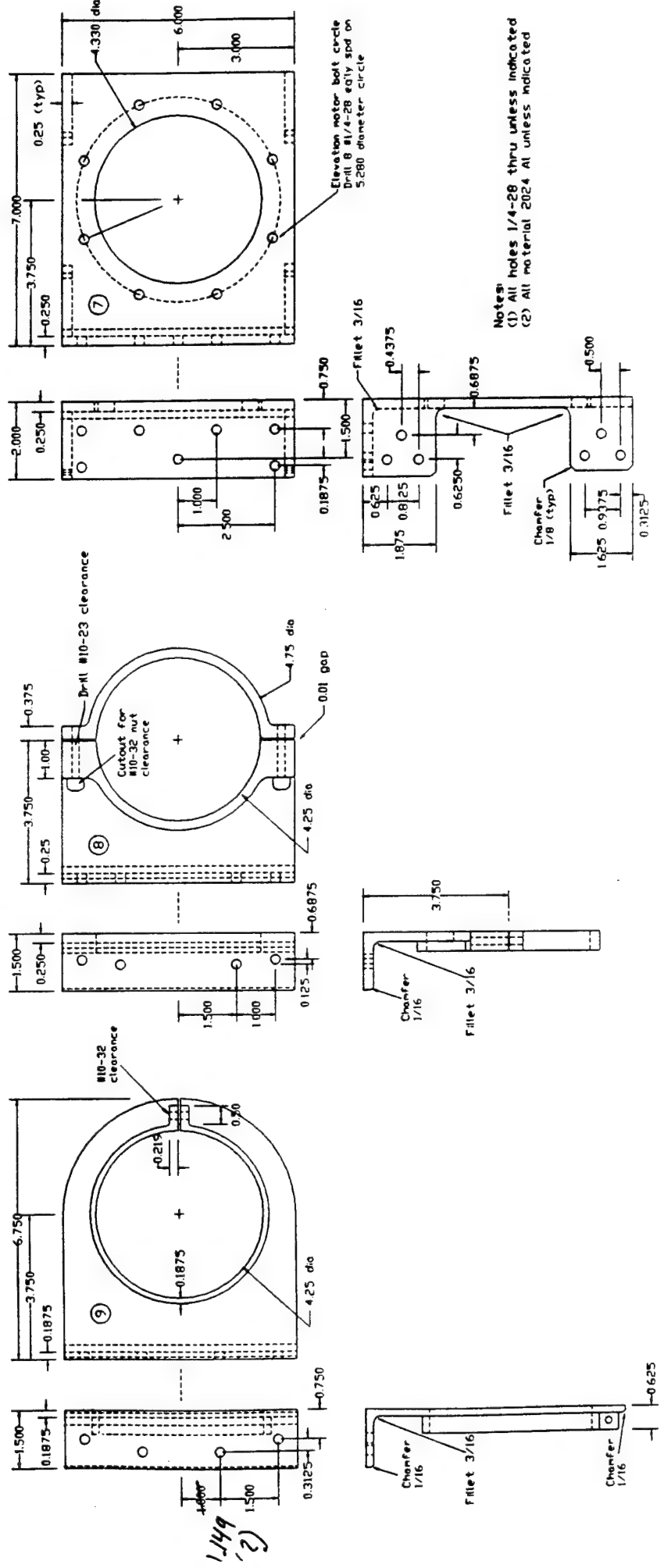
- (1) Material: 2024 T351 aluminum 5/8 thick
- (2) All tapped holes use locking helicoil inserts

# Elevation Motor Mounts

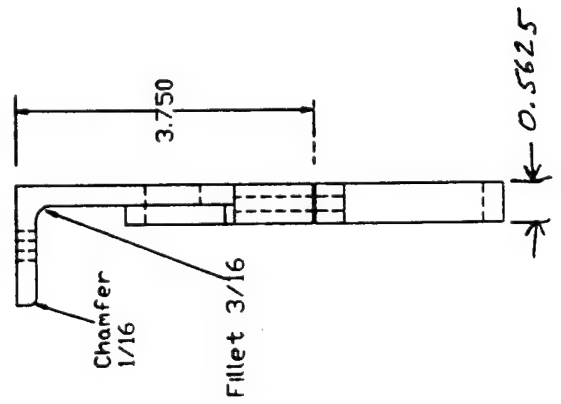
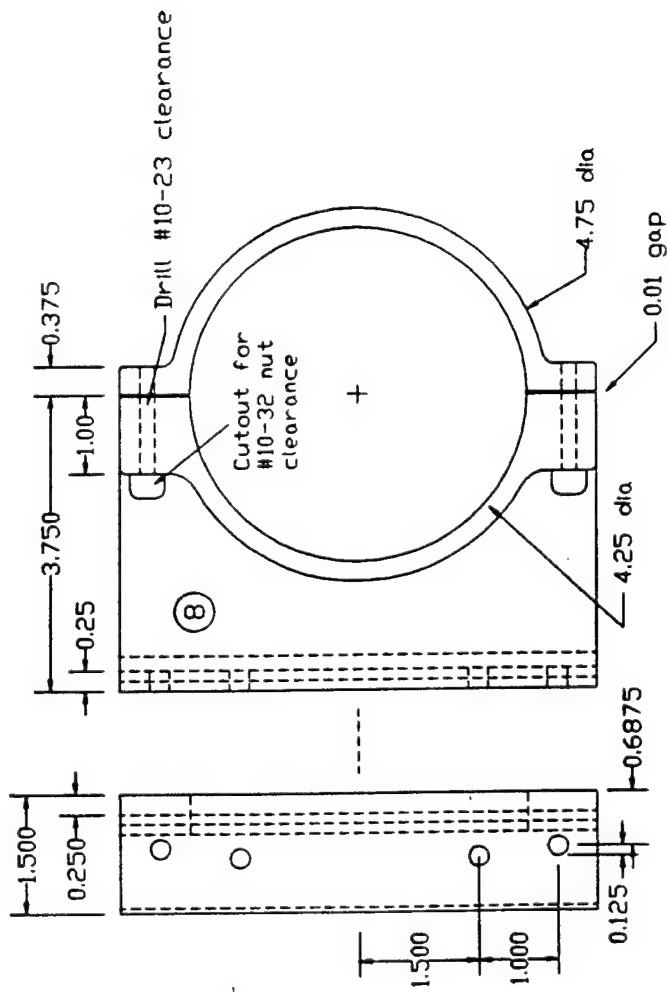
Tertiary

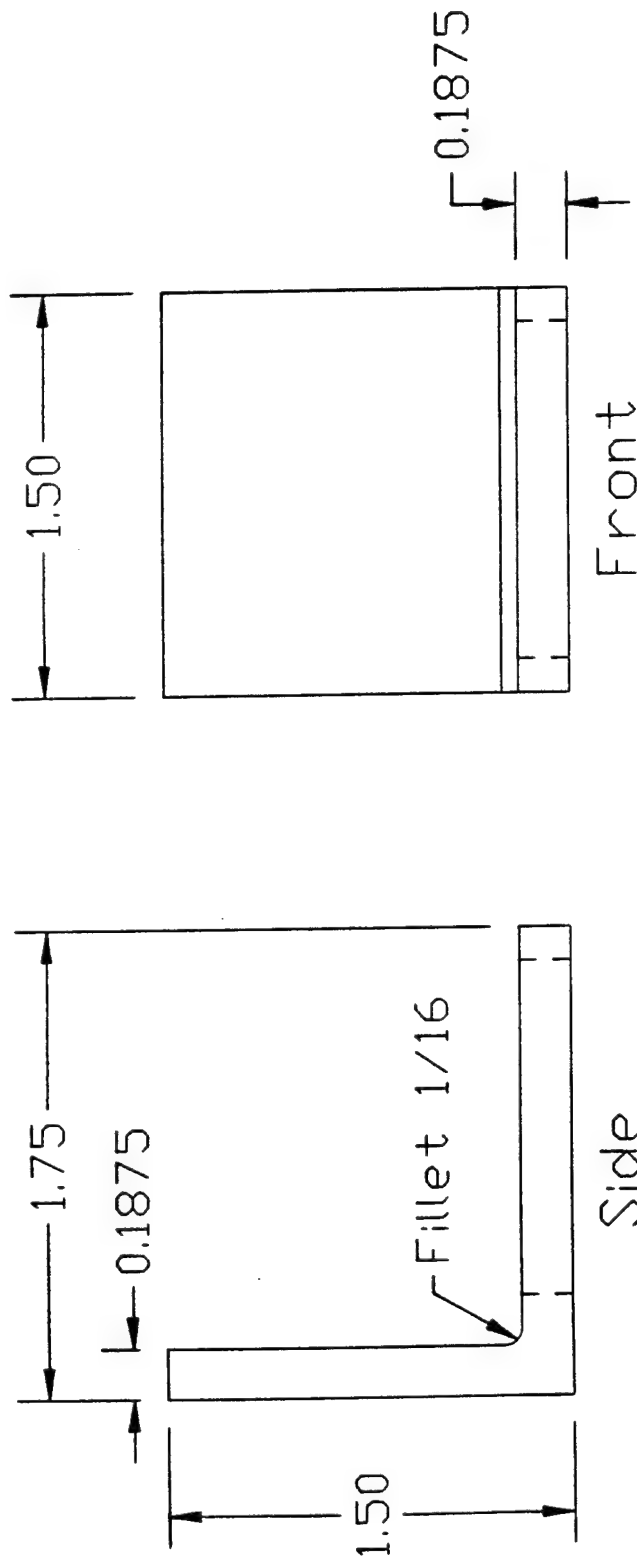
Secondary

Primary

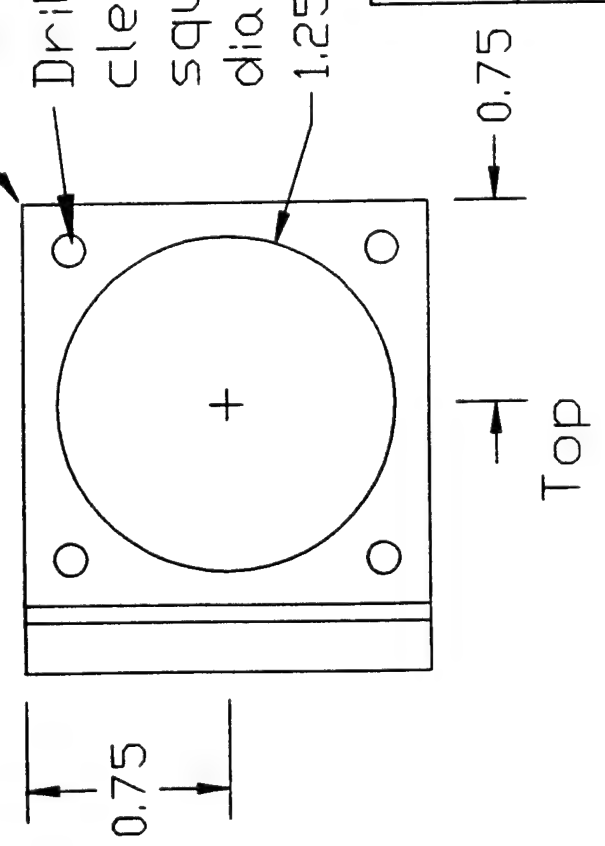


# Secondary

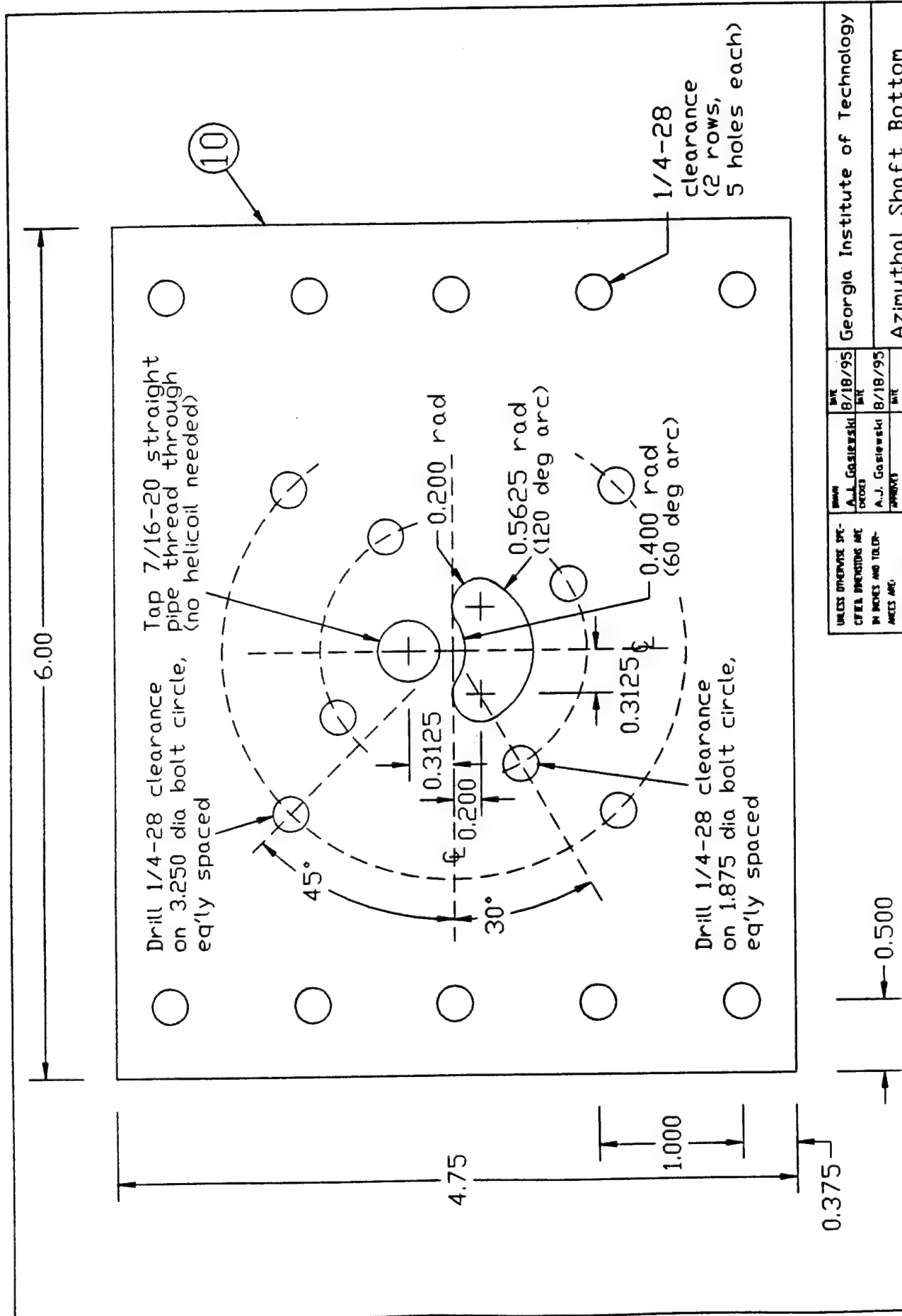




Chamfer 1/8 (typ) *0.120*  
Drill 4 holes ~~0.210~~ dia  
clearance on 1-5/32  
square cnt'd on 1.25  
dia hole.  
-1.25 dia



UNLESS OTHERWISE SPEC- IFIED, MATERIALS ARE TO BE IN ACCORDANCE WITH THE LATEST EDITIONS OF THE SPECIFICATIONS AND TOLER- ANCES ARE TO BE AS SHOWN HEREIN.	MATERIAL:  2024 AL	2 pcs req'd	DATE 8/18/95	ISSUED A.J. GOSIEWSKI	DATE 8/18/95	Georgia Institute of Technology
				DESIGNED A.J. GOSIEWSKI	DATE 8/18/95	
		2 pcs req'd		DRAWING #2		Revision 1.5
				SCALE		SHEET 2



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:	DATE	8/18/95	Georgia Institute of Technology	
	DESIGNED BY	A.J. Gasiewski	Azimuthal Shaft Bottom Plate	
	APPROVED BY	A.J. Gasiewski	Drawing #2	
	DATE	8/18/95	Revision 1.5	
MATERIAL:		2024 Al	SCALE	SHEET 3
		0.25 thick	1 pc req'd	

# Azimuthal Drum Details

The drawing consists of two main views: a side view (left) and a top view (right). The side view shows a cross-section of the drum with a central shaft and various components labeled with circled numbers 1 through 5. Dimensions include a 1/4-20 bolt circle, a 1/2 inch bolt circle, and a 1/4-20 bolt circle. The top view shows the drum from above, with a central shaft and various components labeled with circled numbers 1 through 5. Dimensions include a 1/4-20 bolt circle, a 1/2 inch bolt circle, and a 1/4-20 bolt circle. The drawing also includes a detail view of the bolt circle overlay (top view) and a list of notes.

**Notes:**

- (1) All interior corners filleted using 1/16 radius unless indicated
- (2) All exterior corners chamfered using 1/16 inch
- (3) All components turned from 2024 T351 aluminum stock
- (4) All tapped holes to use locking Helical inserts

**Legend:**

- 1 Azimuthal motor mount drum
- 2 Yoke upper bearing drum
- 3 Yoke upper bearing outer seat
- 4 Yoke upper bearing inner seat
- 5 Yoke upper bearing outer seat

Assembly View

Notes:  
 (1) Thru holes for electrical wires in  
 (4) and (19) not indicated. TBD

Legend:

- 9 Azimuthal motor
- 10 Azimuthal encoder mount
- 11 Azimuthal mounting plate
- 12 Horizontal encoder gears
- 13 Azimuthal slip rings
- 14 Slip ring brush block
- 15 Azimuthal shaft seal
- 16 Yoke upper bearing
- 17 Yoke horizontal plates
- 18 Azimuthal shaft bottom plate
- 19 Gas line connector

# Azimuthal Shaft Details

**Top View**

Drill and tap for #8-32 on 90 deg 2.3125 bolt circle 0.75 deep from top  
 2.750 OD  
 2.625 OD  $\pm .001$   
 1.875 OD  
 1.125 ID  $\pm .005$   
 0.25  
 0.25 (typ)  
 30  
 Drill and tap for #10-32 5/8 deep on opposite sides 3/8 below ridge 'A'  
 Drill and tap 1/4-28 on 90 degree 1.875 bolt circle 1.0 deep from bottom of shaft  
 Note: All threaded holes to use locking helical inserts  
 1 Azimuthal shaft (304 stainless steel)  
 2 Keyway (1/4" square, length as indicated, steel)

**Side View**

1/32 Fillet  
 0.25  
 1.00  
 Drill and tap for 1/4-28 set screws (two locations)  
 0.25  
 Drill 3/8" clearance on 90 deg circle to center of shaft for electrical wire feeds  
 Slant hole 20 deg as shown  
 0.375  
 0.625  
 1.875  
 0.1875  
 Ridge 'A'  
 7.1875  
 1  
 2

Top View

6 Yoke upper bearing inner seat

7 Yoke upper bearing outer seat

8 Azimuthal shaft block

PSR-2 Azimuthal Shaft Assembly

Revision 1.4

Drawing #3

SCALE

SHEET

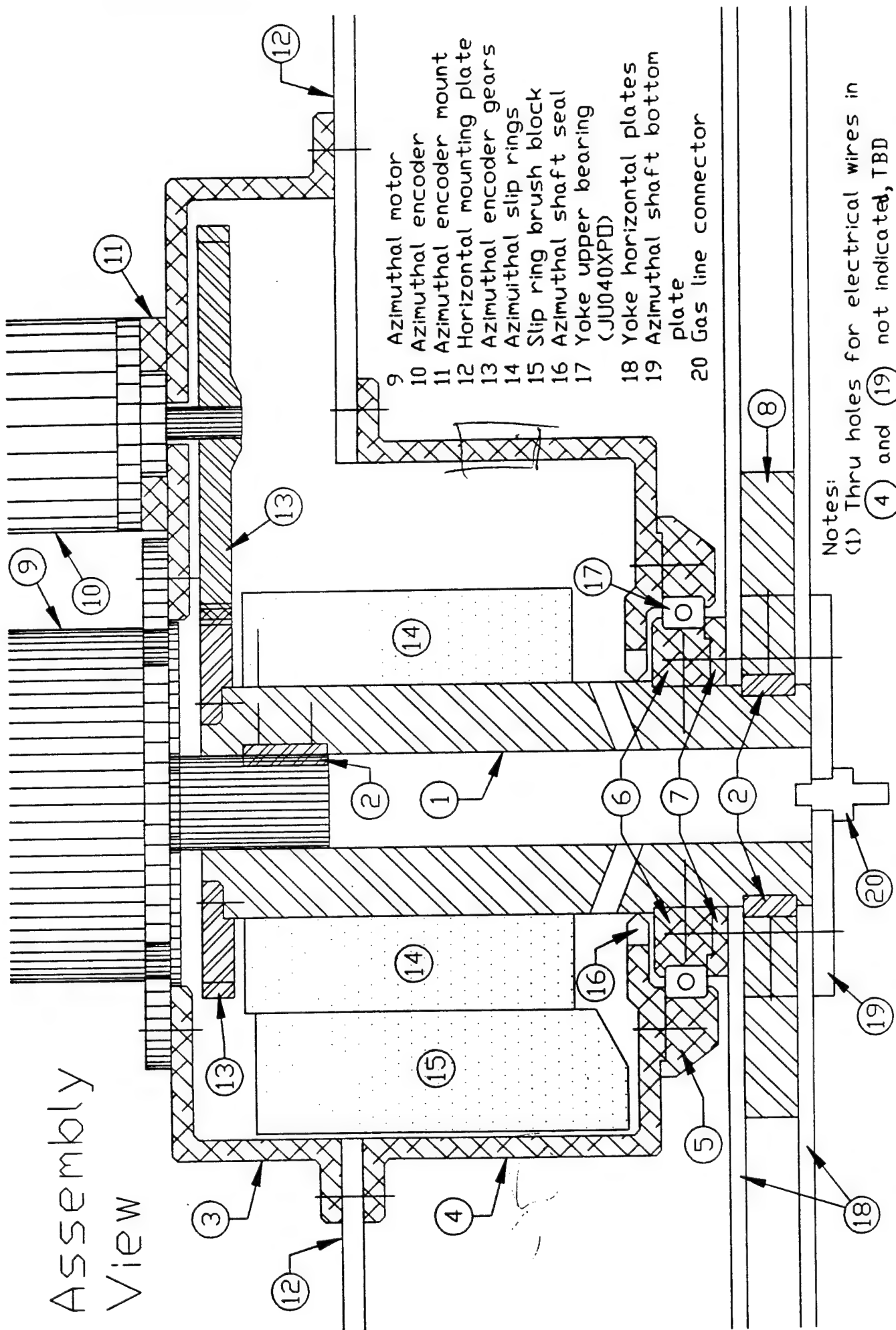
Georgia Institute of Technology  
PSR-2 Azimuthal Shaft  
Assembly

Drawing #3 Revision 1.4

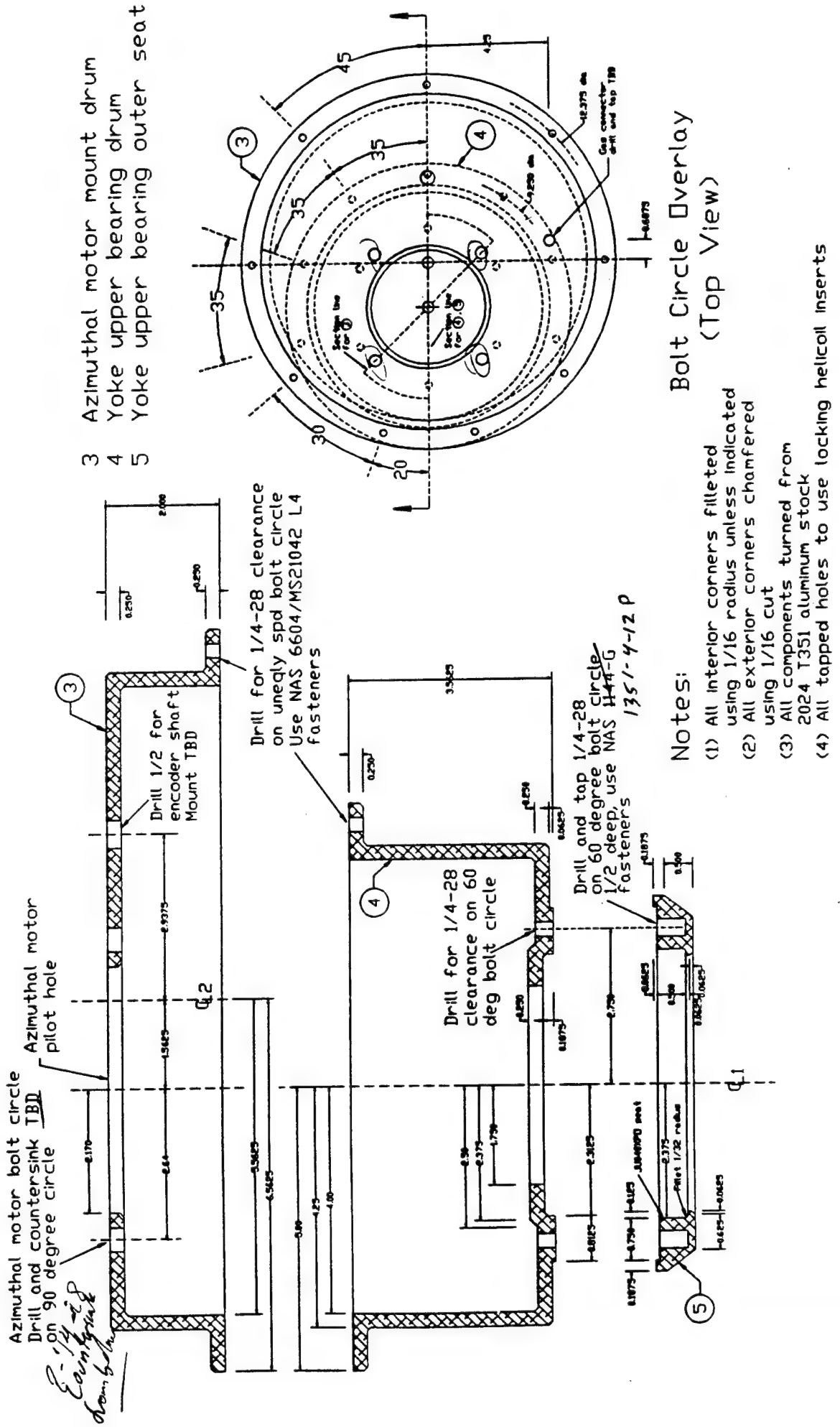
SCALE				SHEET
-------	--	--	--	-------



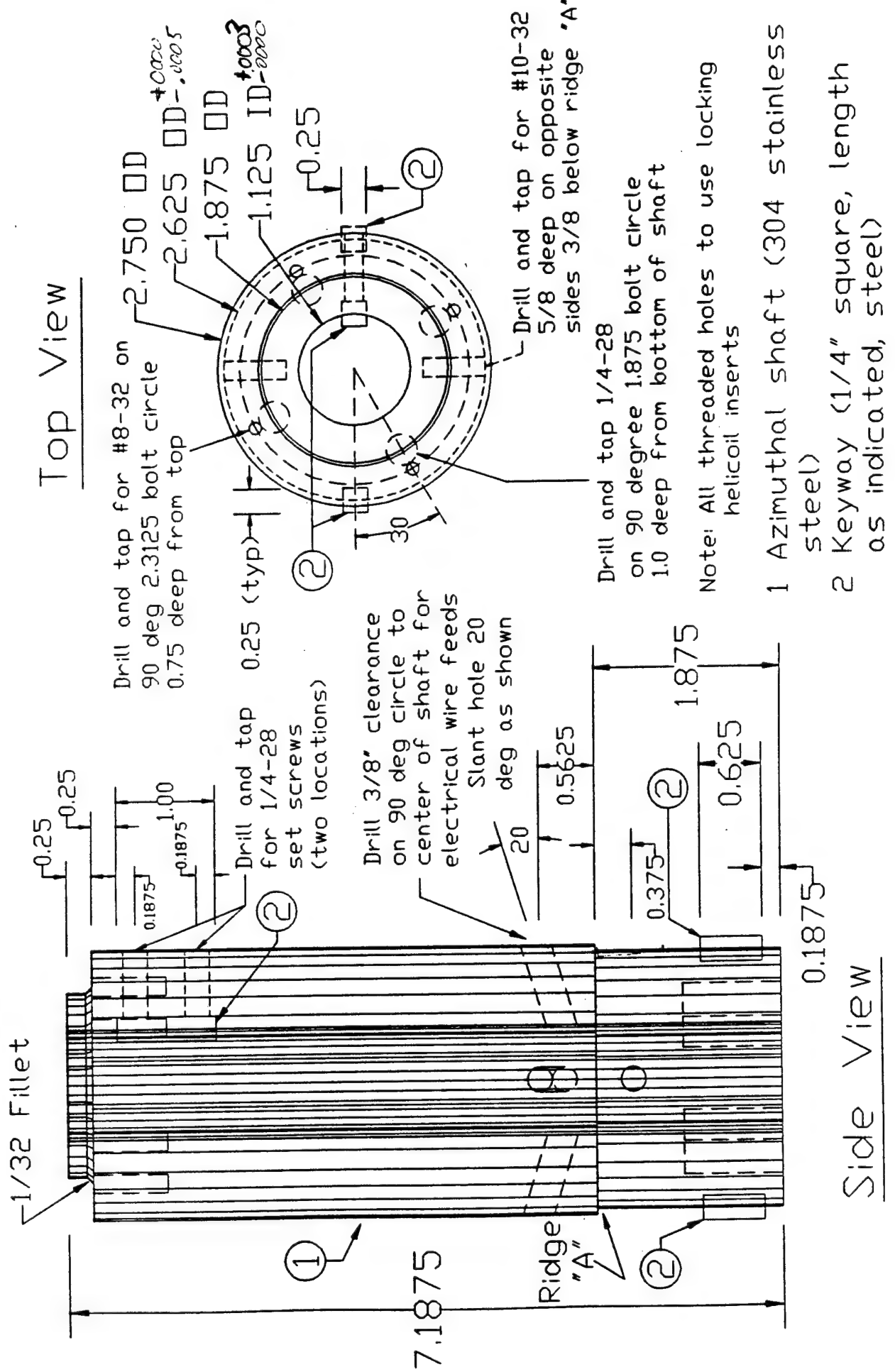
# Assembly View



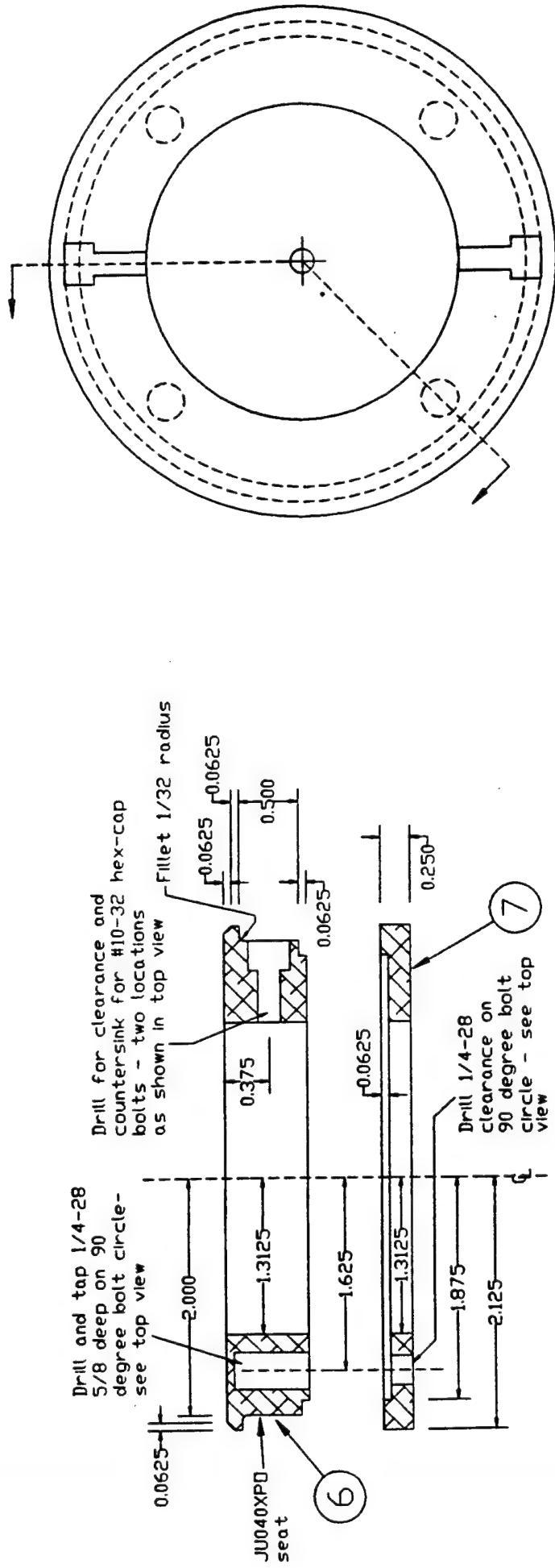
# Azimuthal Drum Details



# Azimuthal Shaft Details



# Upper Bearing Inner Seat Details



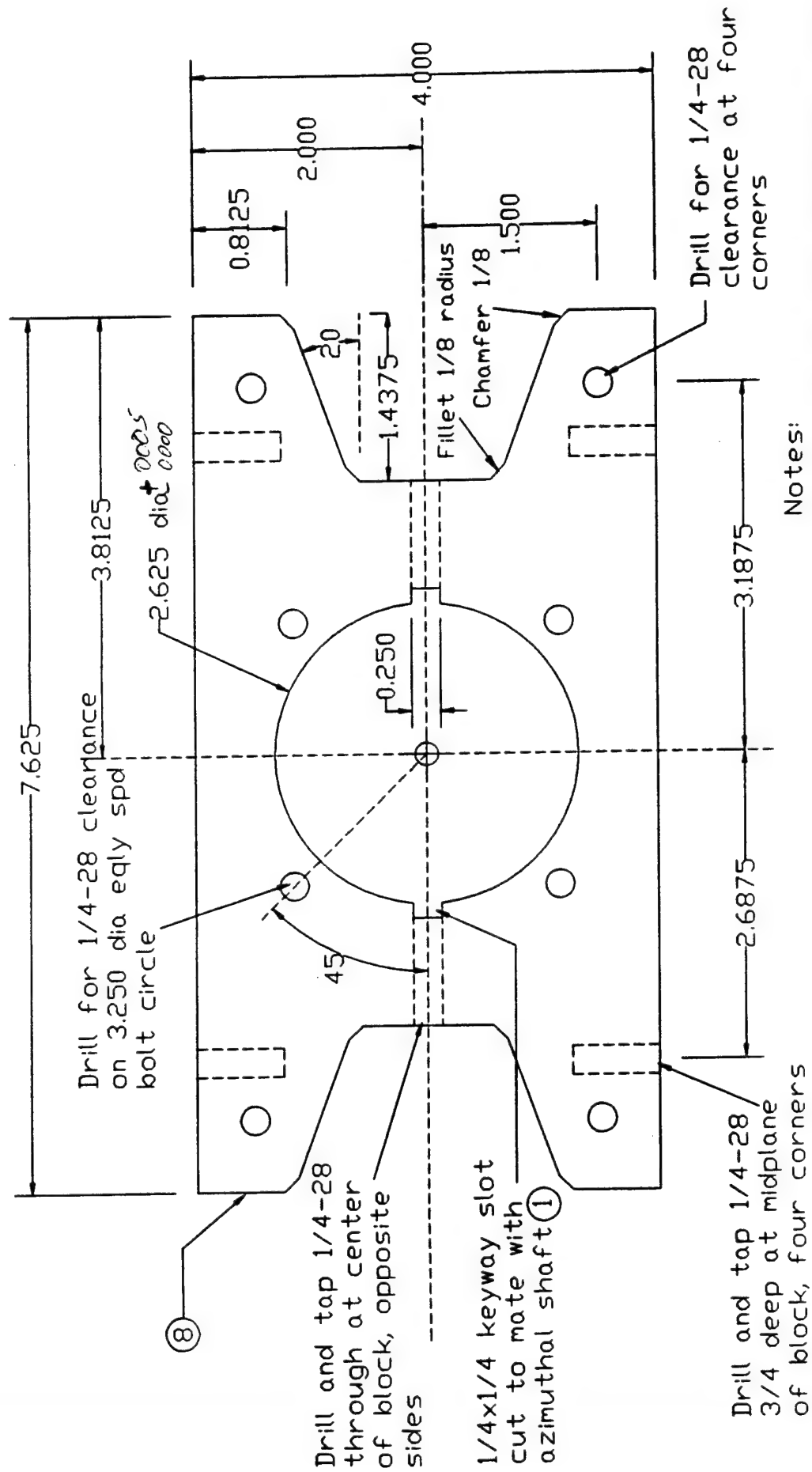
Top View

## Notes:

- (1) Material: 2024 T351 Aluminum
- (2) All tapped holes use locking helicoil inserts

- 6 Yoke upper bearing inner seat
- 7 Yoke upper bearing shim

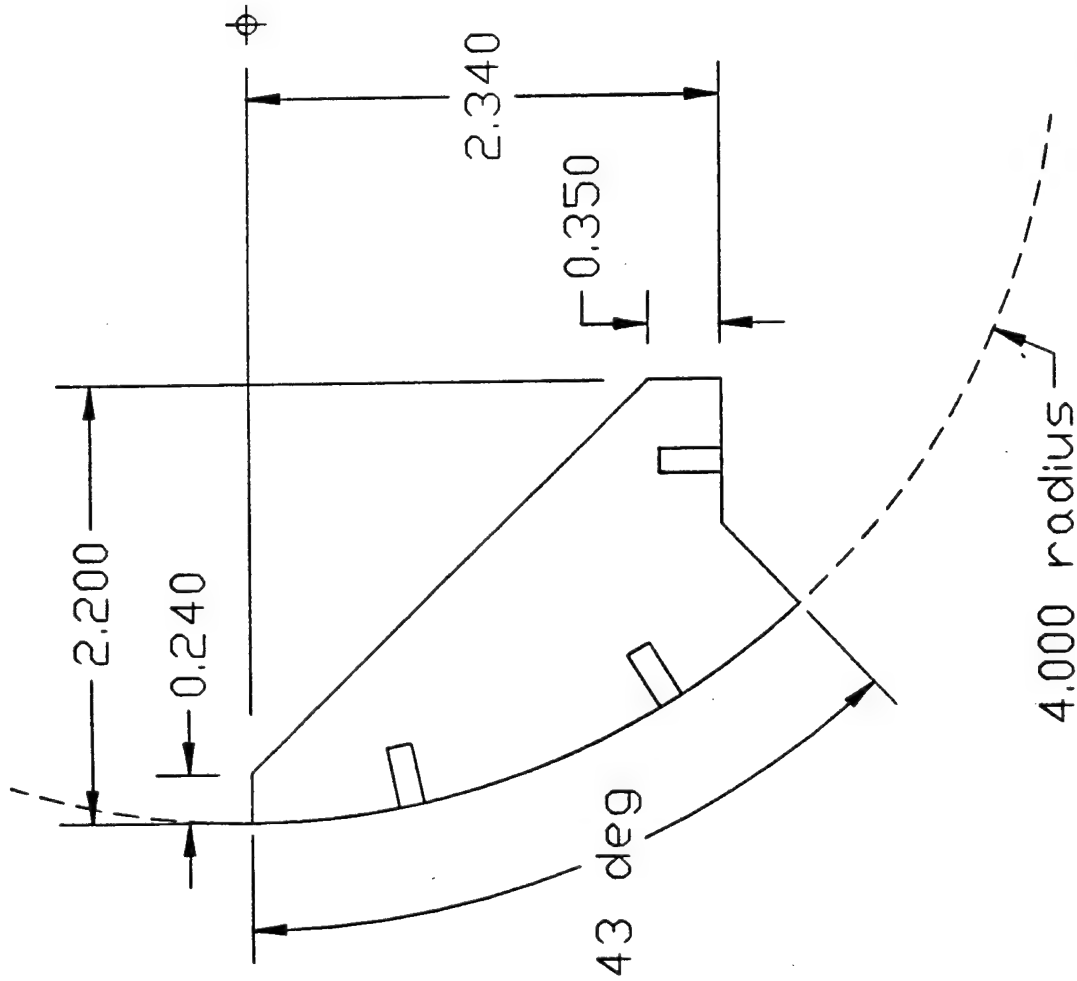
# Azimuthal Shaft Block Details



8 Azimuthal shaft block

Notes:

- (1) 5/8 thick 304 stainless steel
- (2) All threaded holes to use locking helicoil inserts



- (1) Make two pieces of height 4.00 each
- (2) Do not drill or tap

Top View

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES AND TOLERANCES ARE: XX $\pm .01$ XX $\pm .005$	DATE	12/21/95	Georgia Institute of Technology	
	BY	A.J. Gasiewski		
	DATE	12/21/95	Brush Block Mounts	
	BY	A.J. Gasiewski		
2 pcs req'd			Drawing #3	Revision 1.4
SCALE				SHEET 3

MATERIAL:  
6061 Al

**Top View**

12 outer seats spd evenly on 30 deg circle along with two inner seats to capture KG300XPD bearing

Scallops for optical encoder cable

MS21075L4 capture nuts (6 per flange plate, flush-riveted to top side)

Inner flange plate (idle side)

Center of outer flange plate

31.375 dia cutout in outer flange plate

Outer bearing seat (12 req'd)

Inner bearing seat (2 req'd)

Inner flange plate (drive side)

Scallops for scanhead power cable

N2 feedthrough

TNC feedthroughs

30.0"

20"

3.5"

70"

**Detail D**

Small scallop for idle side

Note: For idle side flange plate cut small cable scallop and do not drill TNC or N2 feedthrough holes

Detail C (drive side)

Detail A

Small scallop  
for idle side

Note: For idle side flange plate cut small cable scallop and do not drill TNC or N2 feedthrough holes

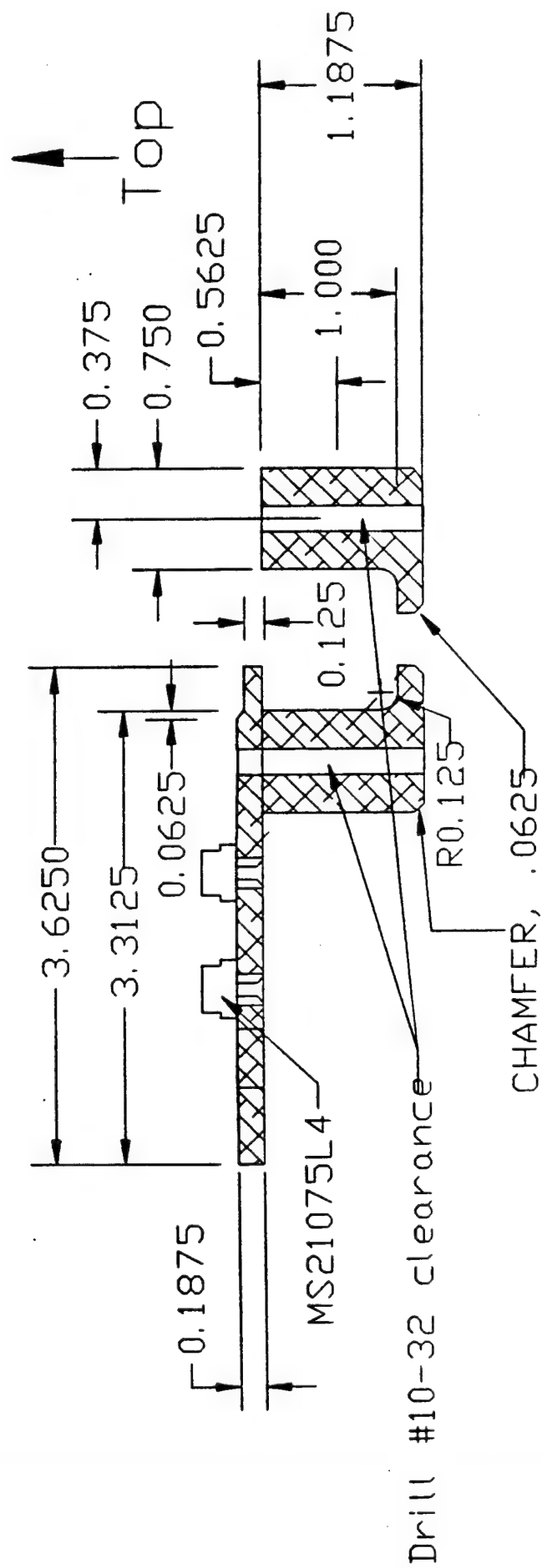
### Detail A



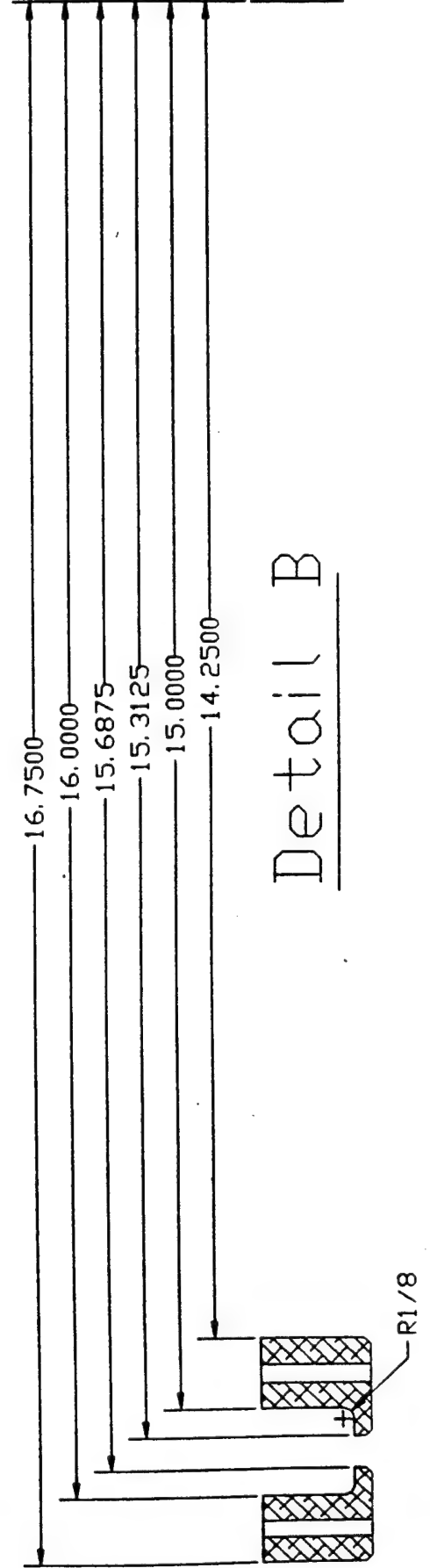
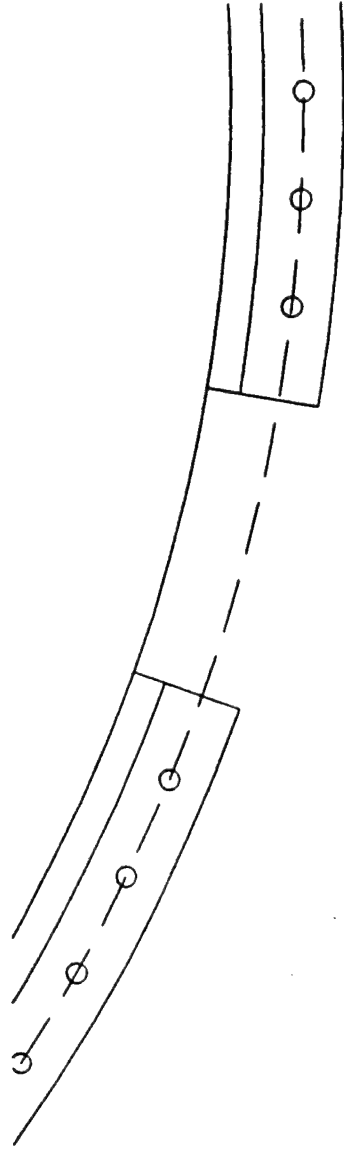
Detail C  
(drive side)

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:		FRACTIONS XX XX XX XX XX XX		DECIMALS XX XX XX XX XX XX		DATE 6/10/95 DATE 8/18/95 DATE DATE		PROJECT ERIC PANNING DEVICES AJ GASTIEVSKI DEVICES		DATE 6/10/95 DATE 8/18/95 DATE DATE		Georgia Institute of Technology	
MATERIAL				2024 Al				DRAWING #4 DRAWING #4 DRAWING #4		PSR-2 LOWER BEARING INNER AND OUTER SEATS AND FLANGE REVISION 1.4			

### Detail B



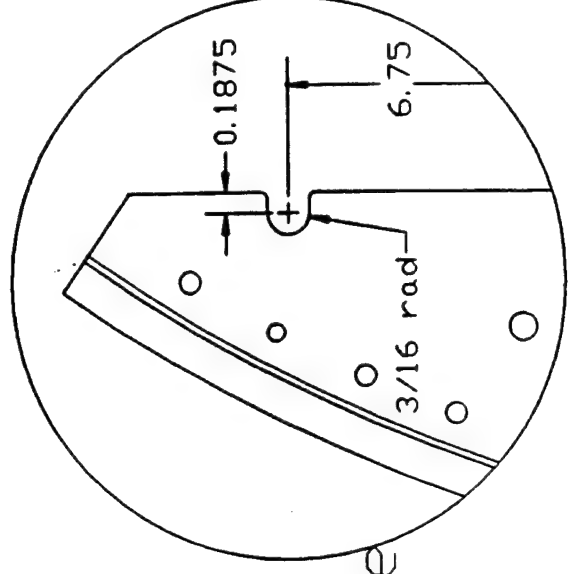




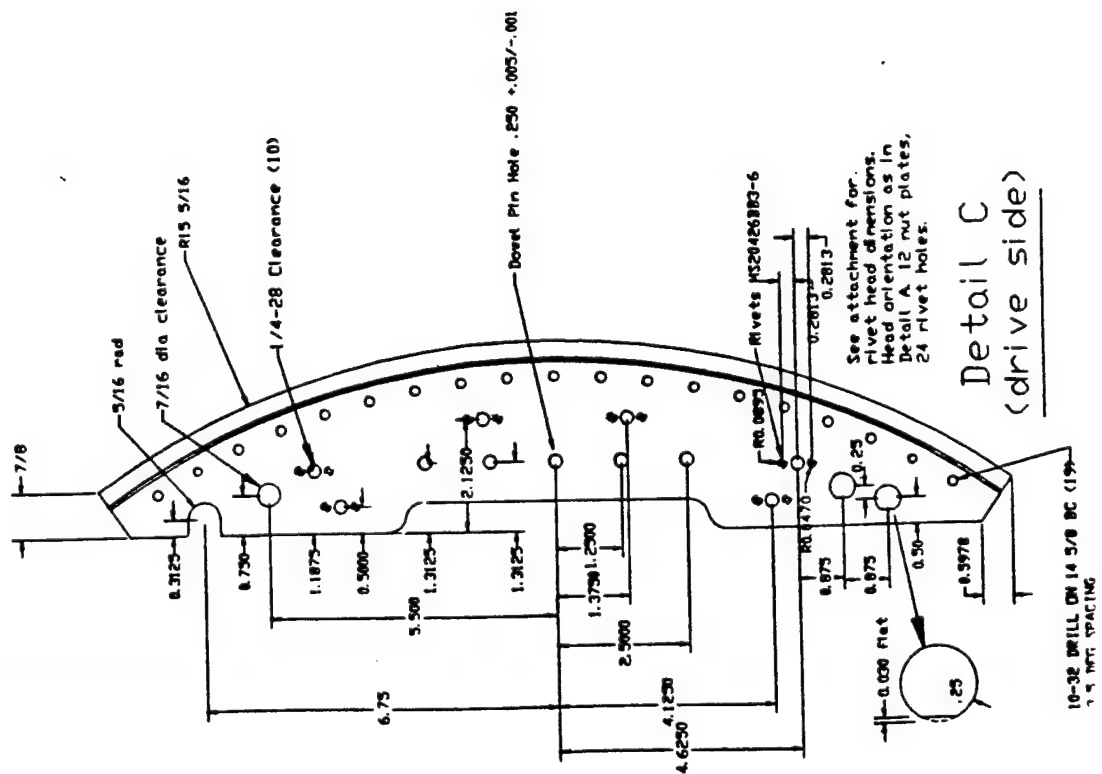
Detail B

## Detail D

### Small scallop for idle side

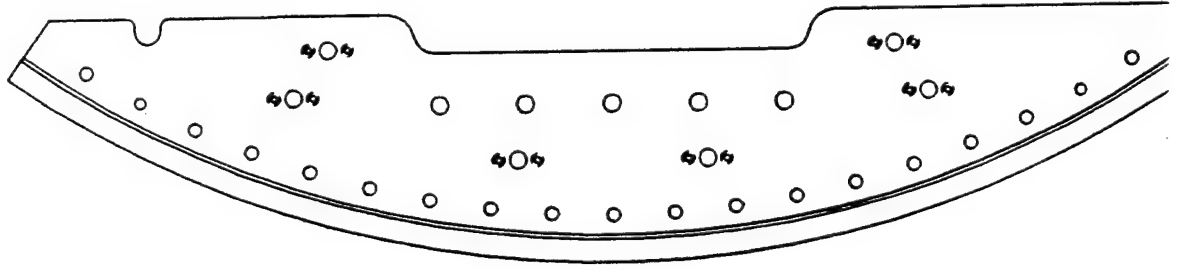


Note: For idle side flange plate  
cut small cable scallop  
and do not drill TNC or  
N2 feedthrough holes



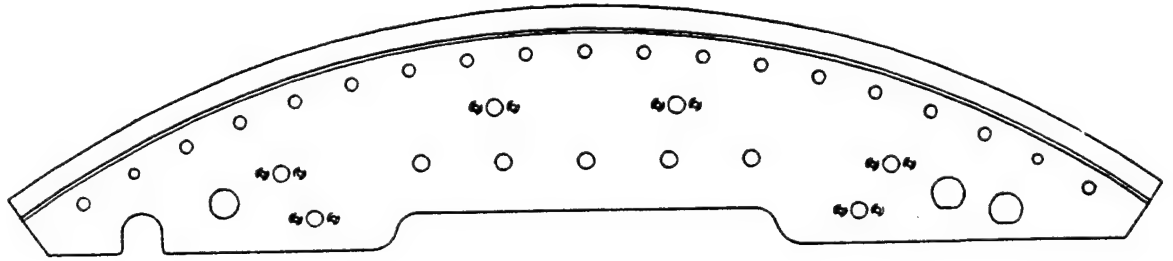
Idle Side Inner Flange Drawing For CNC  
Refer to Drawing 4 for specifications and  
orientation for rivet holes

This file is INIDLE.DWG

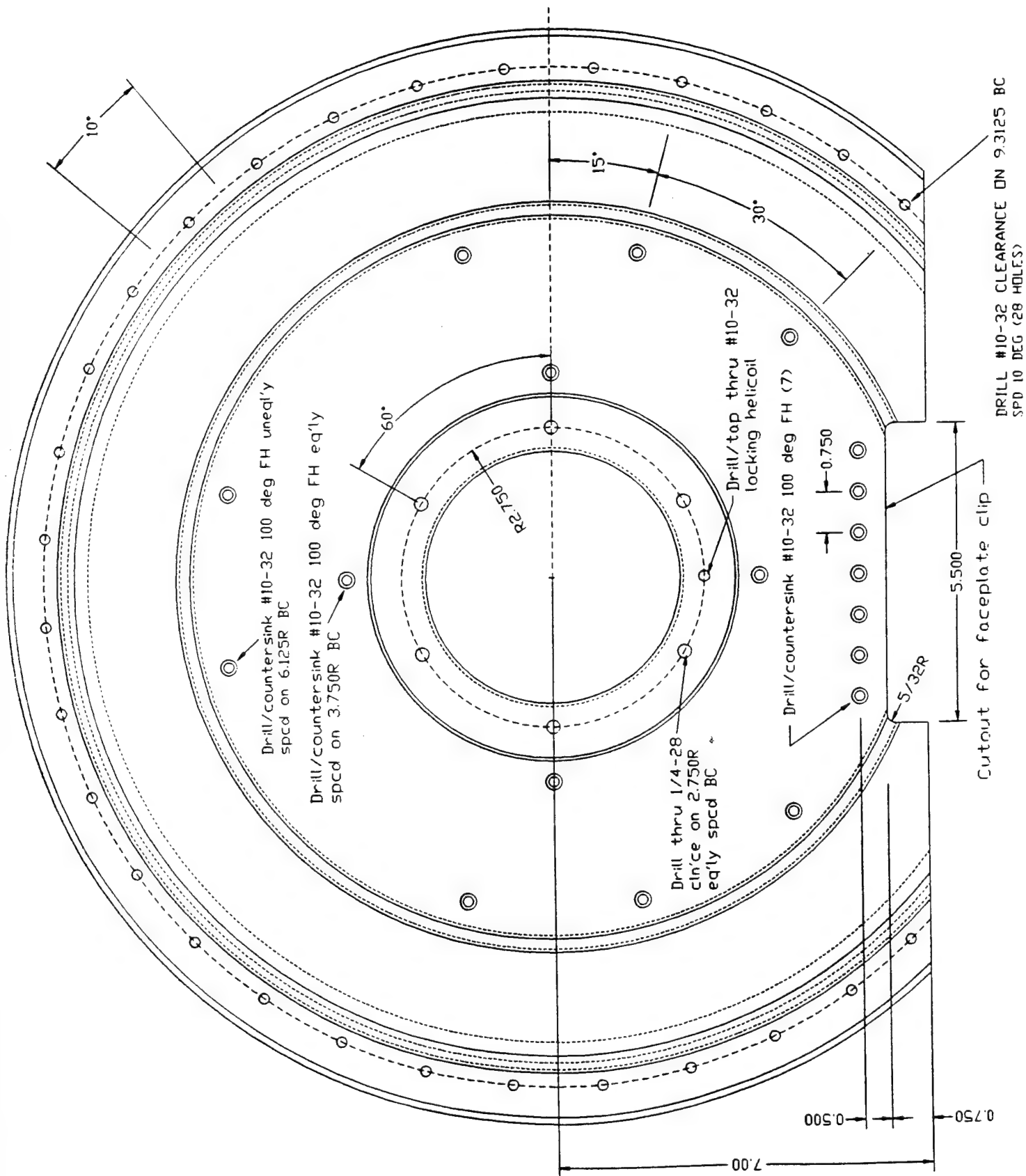


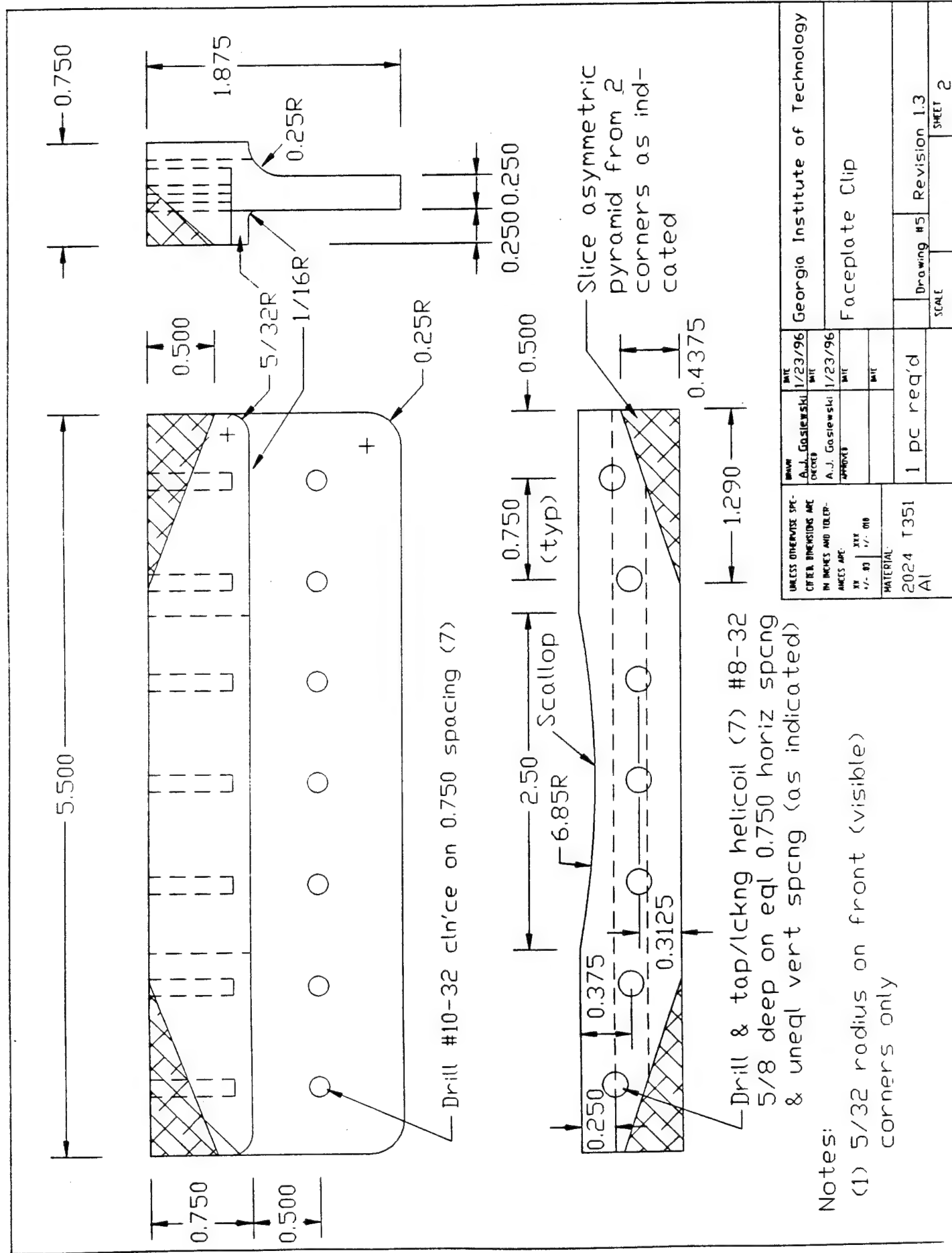
Drive Side Inner Flange Drawing for CNC.  
Refer to Drawing 4 for specifications and  
orientation for rivet holes.

This file is INDRI.DWG







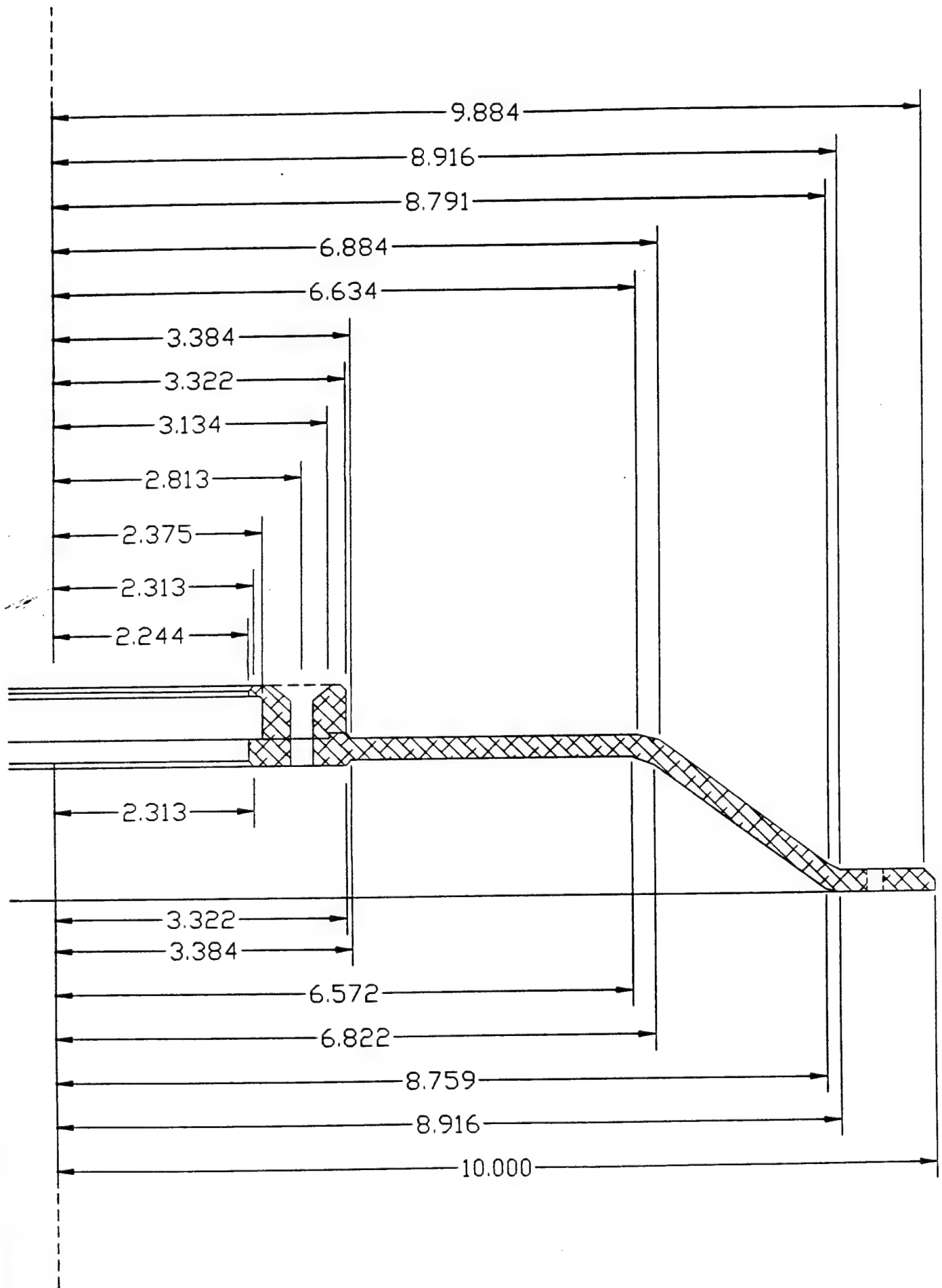


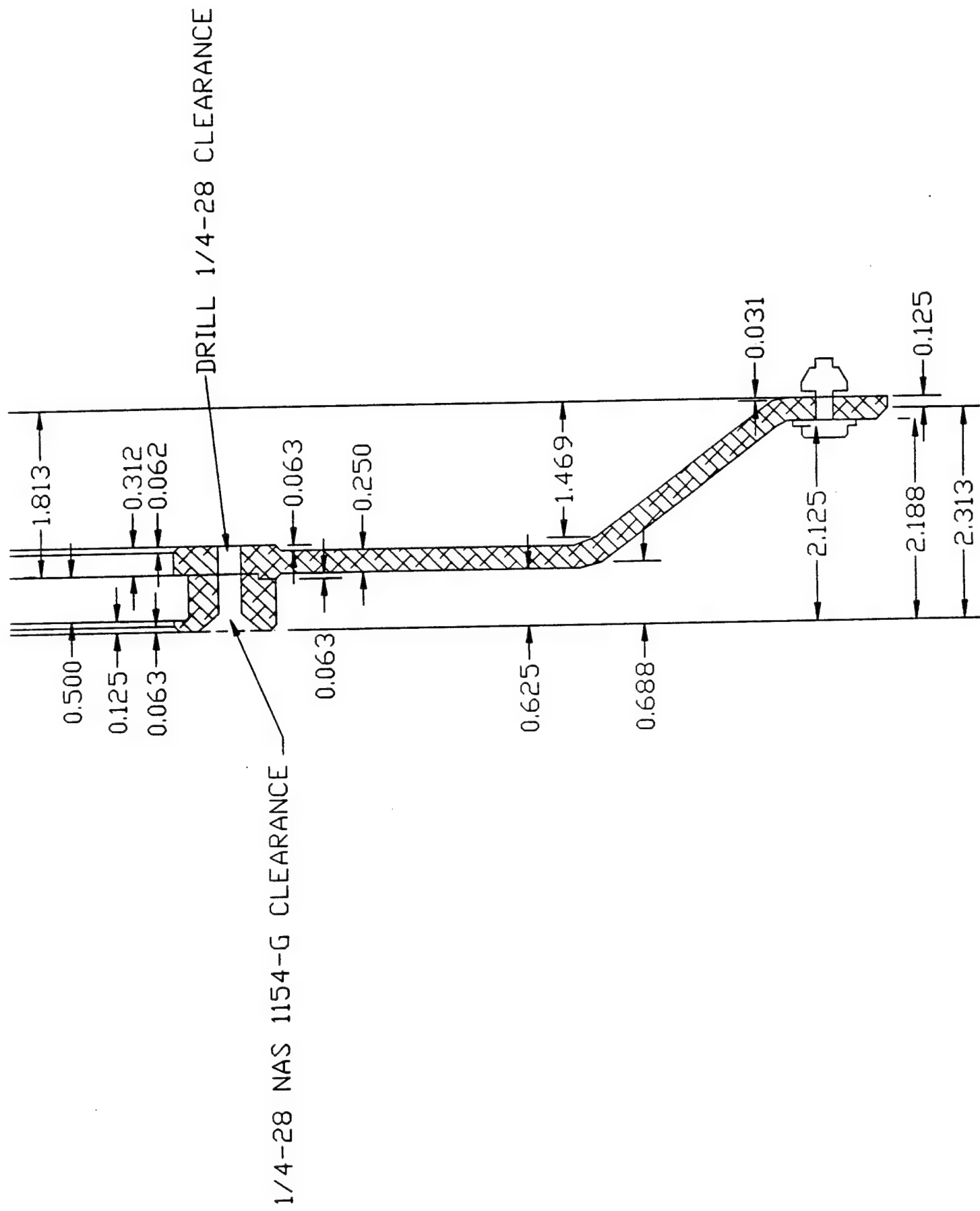
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND DECIMALS ARE XX		DATE	DATE	DATE	DATE
DESIGNED BY	A.J. Gasiewski	1/23/96	DATE	DATE	DATE
CHECKED BY	A.J. Gasiewski	1/23/96	DATE	DATE	DATE
APPROVED BY			DATE	DATE	DATE
MATERIAL		1 pc req'd			
2024 T351 Al		Drawing #5			
		Revision 1.3			
		SHEET 2			

Georgia Institute of Technology

Faceplate Clip



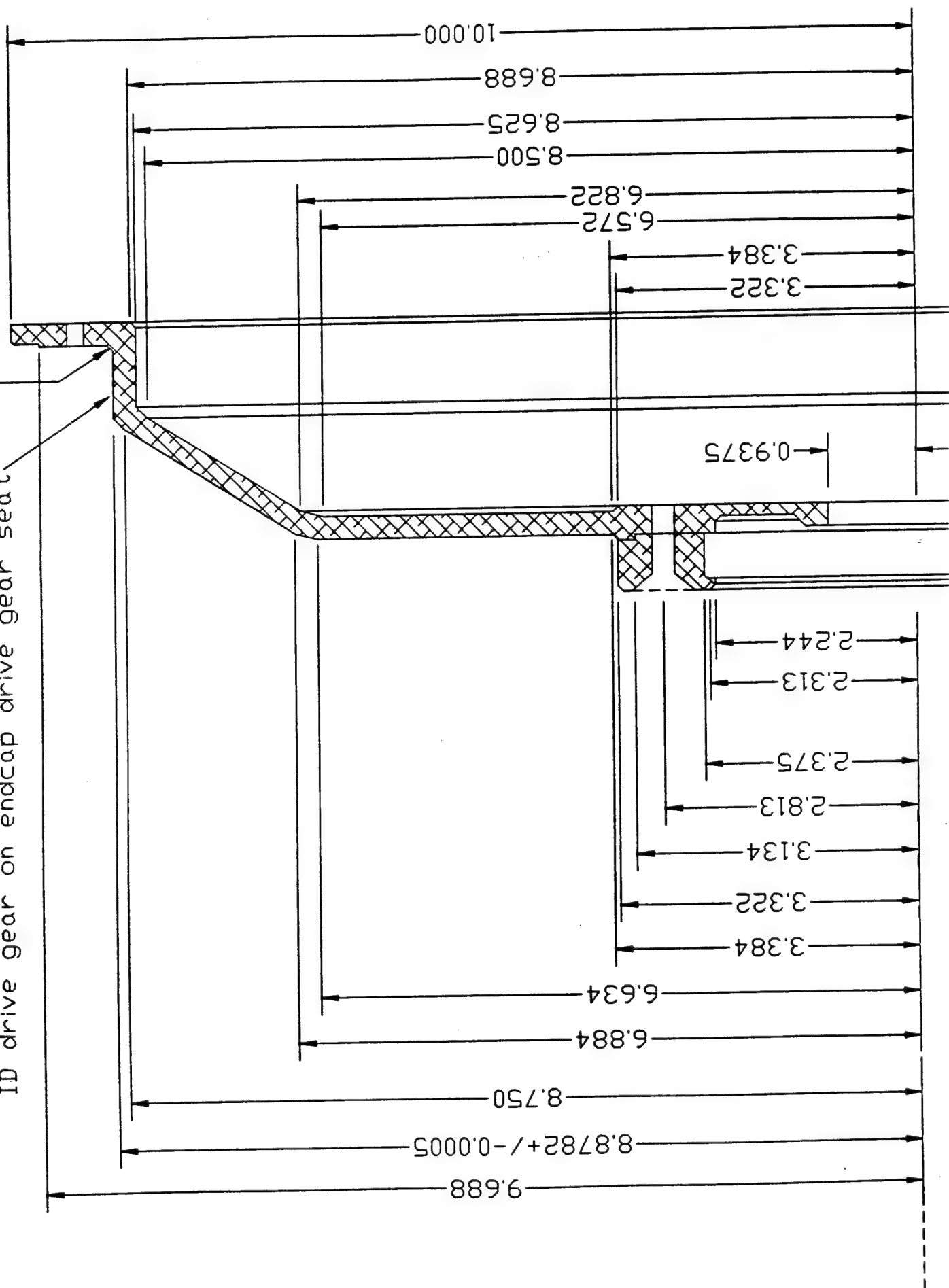


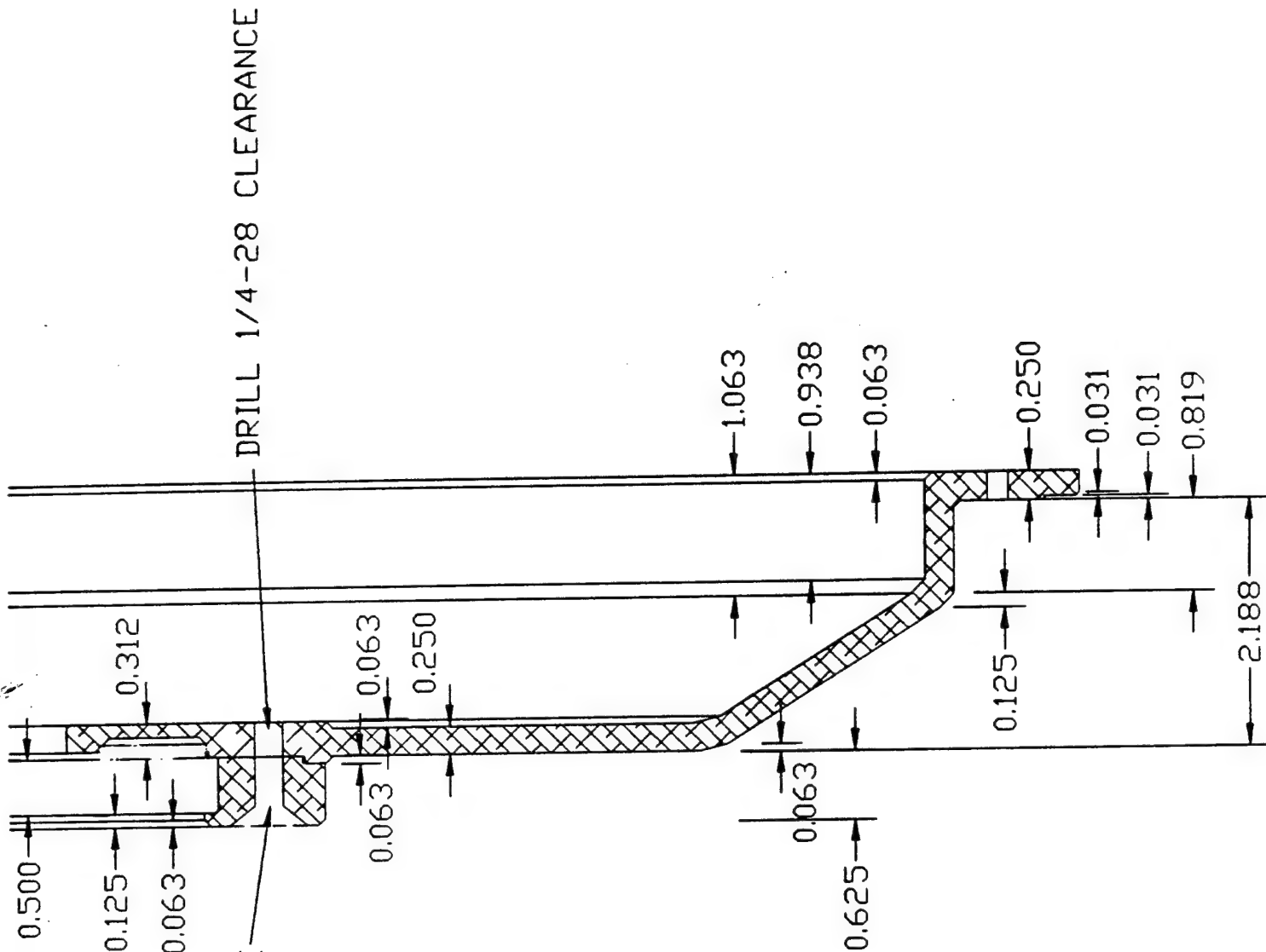




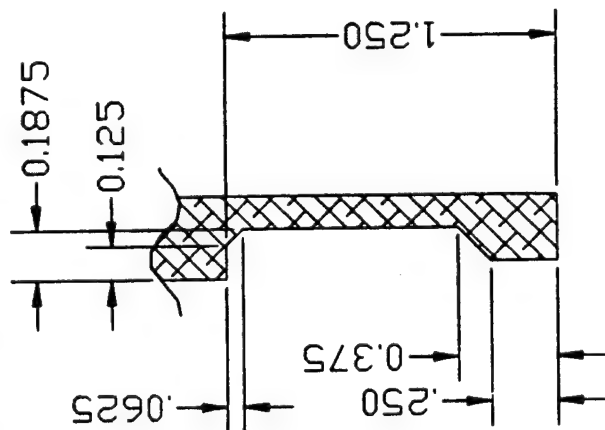
Fillet 1/16 radius

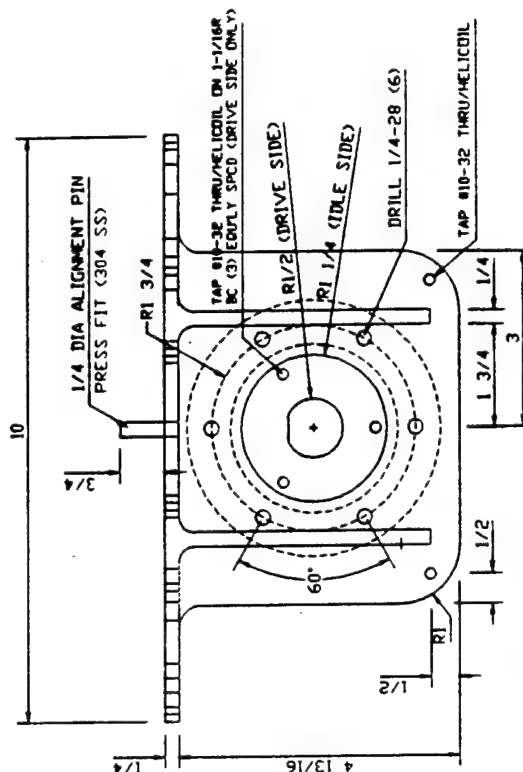
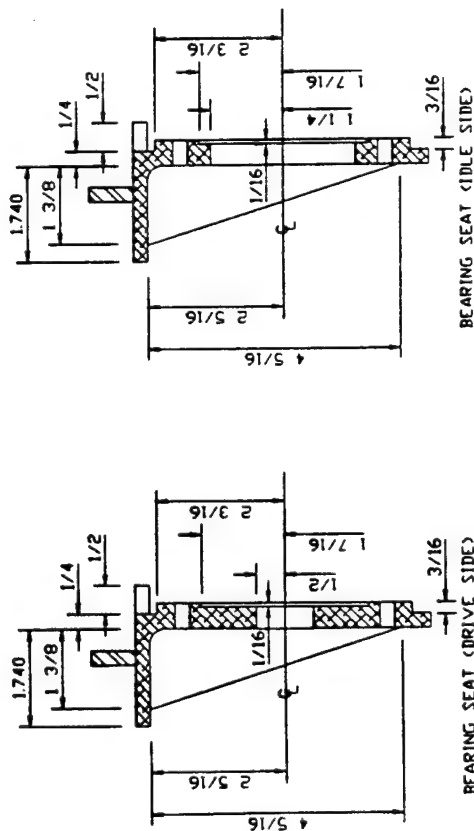
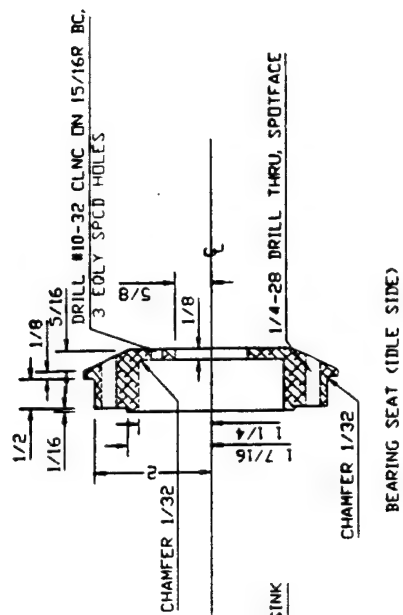
Note: 0.0032" radius int. fit at 20 deg C to 17.750"  
ID drive gear on endcap drive gear seat





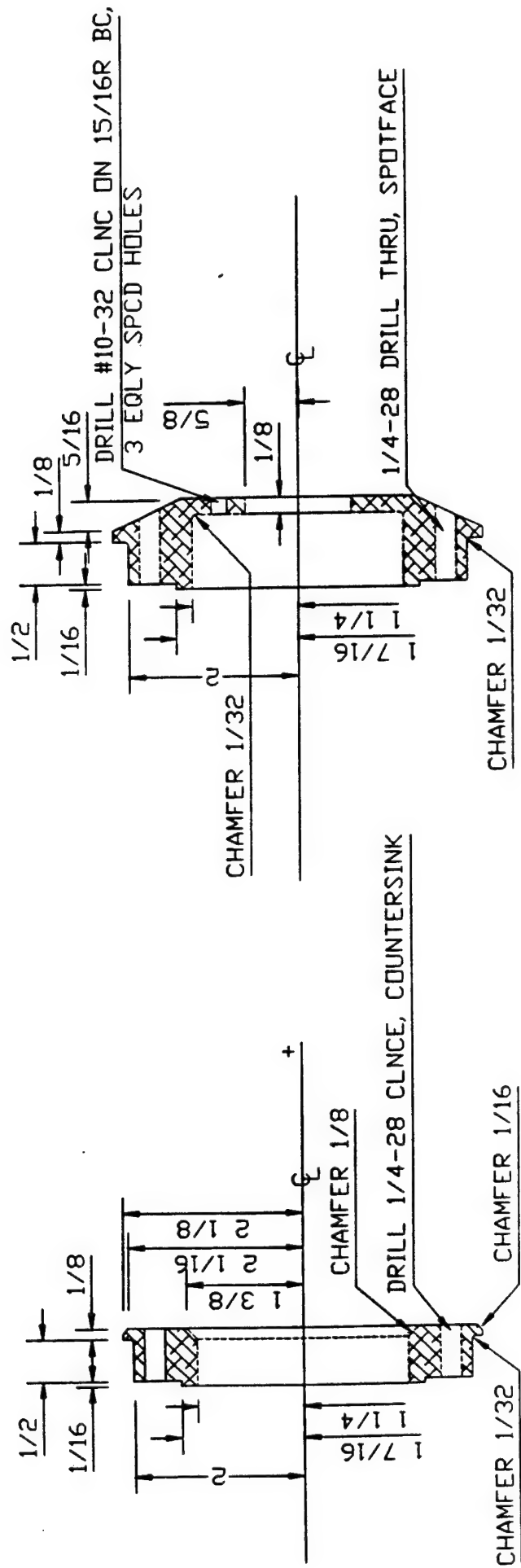
DETAIL OF INNER RING AREA





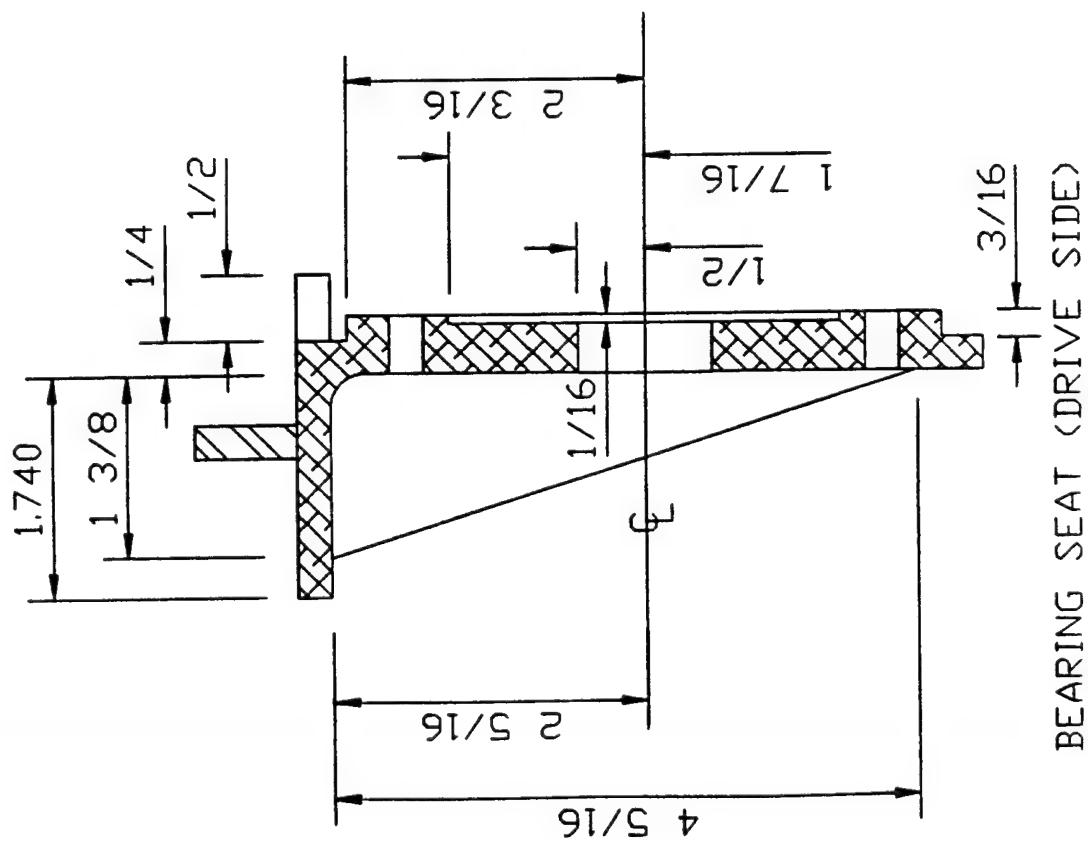
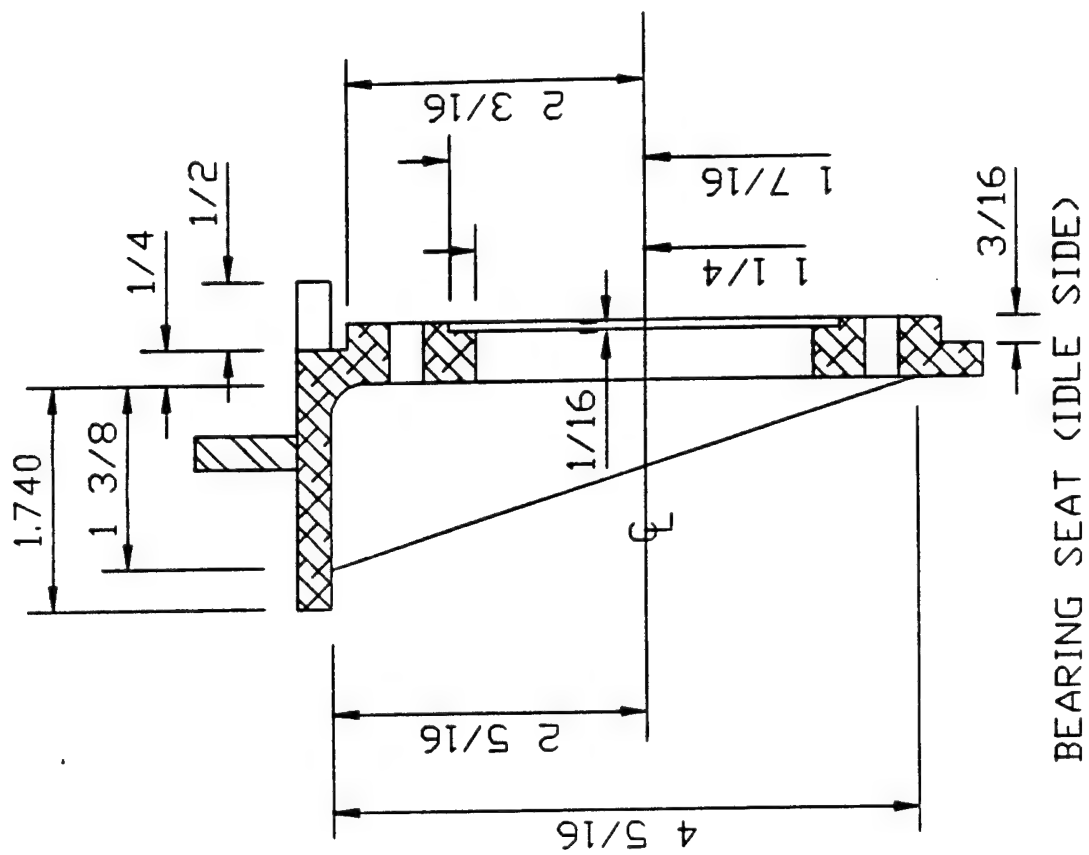
- NOTES: (1) ALL FILLETS 1/4R UNLESS INDICATED  
(2) ANGLE BRACKET AND BEARING SEAT FROM SOLID AL STOCK  
(3) TO DRILL 10 1/4-28 HOLES, FIRST FIT ALIGNMENT PIN THEN  
LOCATE ON INNER FLANGE PLATE, DRILL INNER FLANGE PLATE  
AND ELEVATION BRACKET SIMULTANEOUSLY.  
(4) FLAT IN DRIVE SIDE CENTER HOLE TO FIT AIRFLIGHT SLIP  
RING SHAFT

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE AS SHOWN.		ERIC PARKING		6/18/95		Georgia Institute of Technology	
PROJECT		AJ GASIEWICKI		6/12/95		PSR-2 ELEVATION	
DRAWING		BY				BRACKETS AND SEATS	
DATE		2024.01		DRAWING #6		REVISION 1.4	
UNLESS OTHERWISE INDICATED		ELEV.BRCK.DWG		SHEET		SHEET 1	

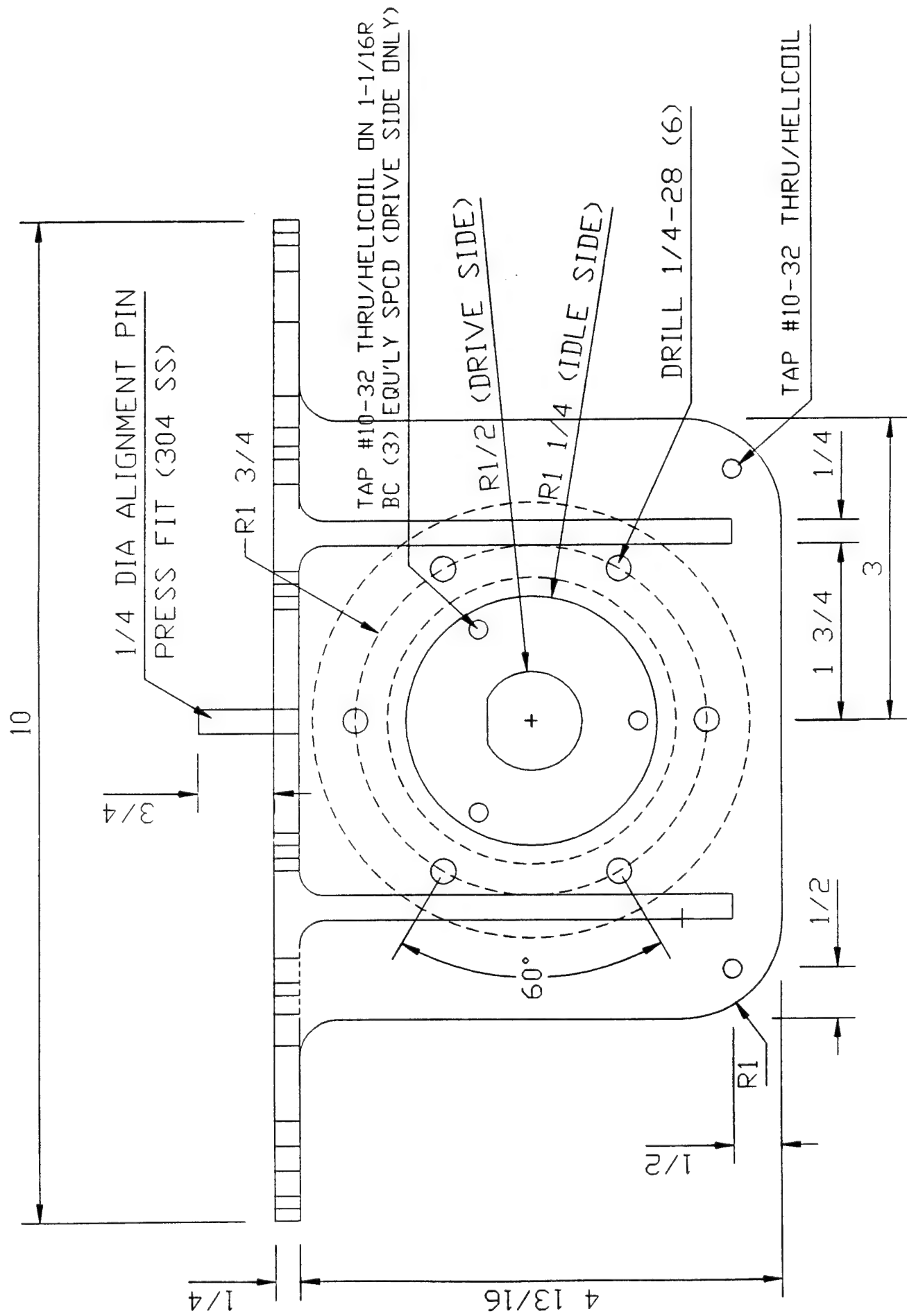


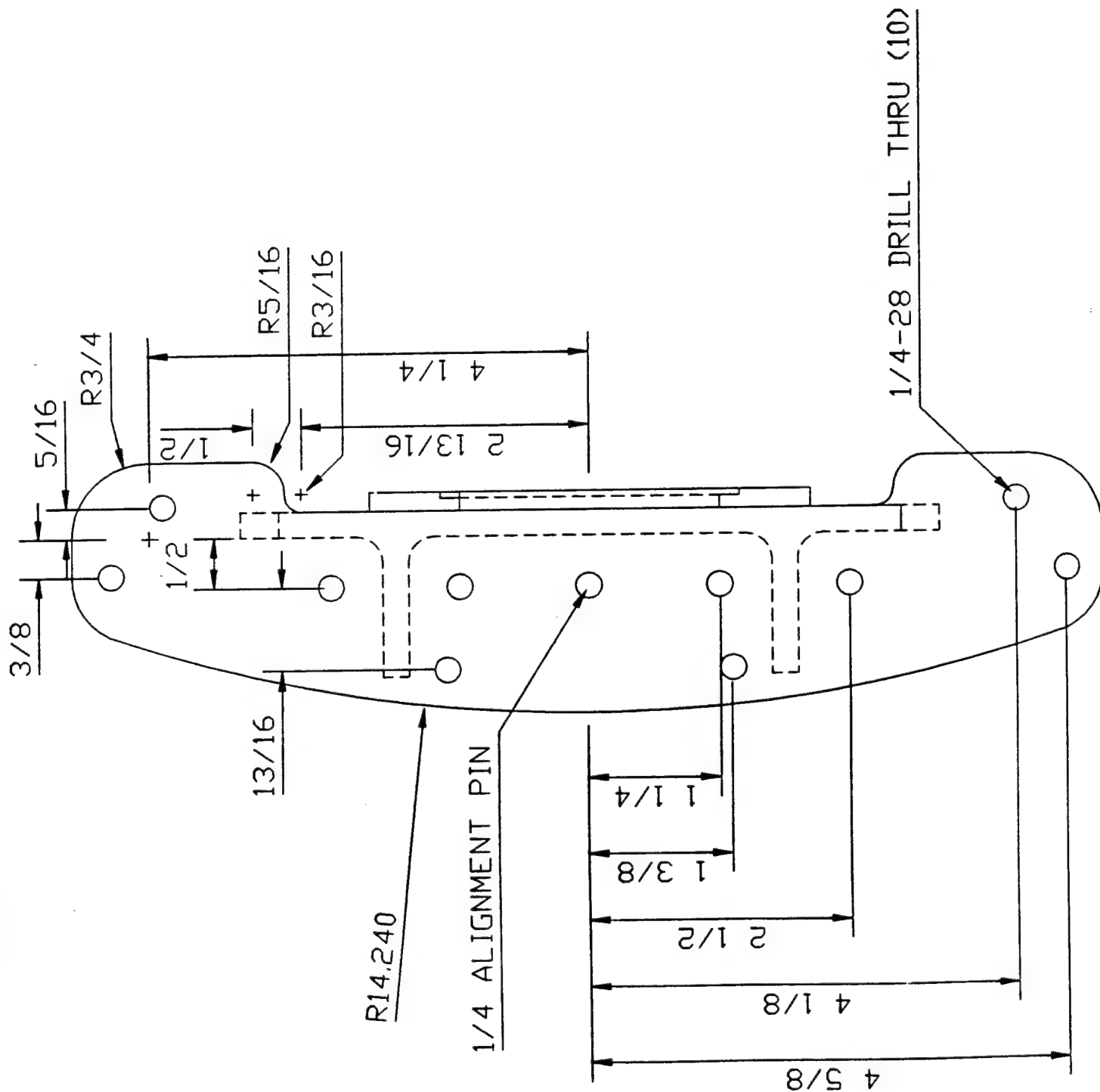
BEARING SEAT (DRIVE SIDE)

BEARING SEAT (IDLE SIDE)

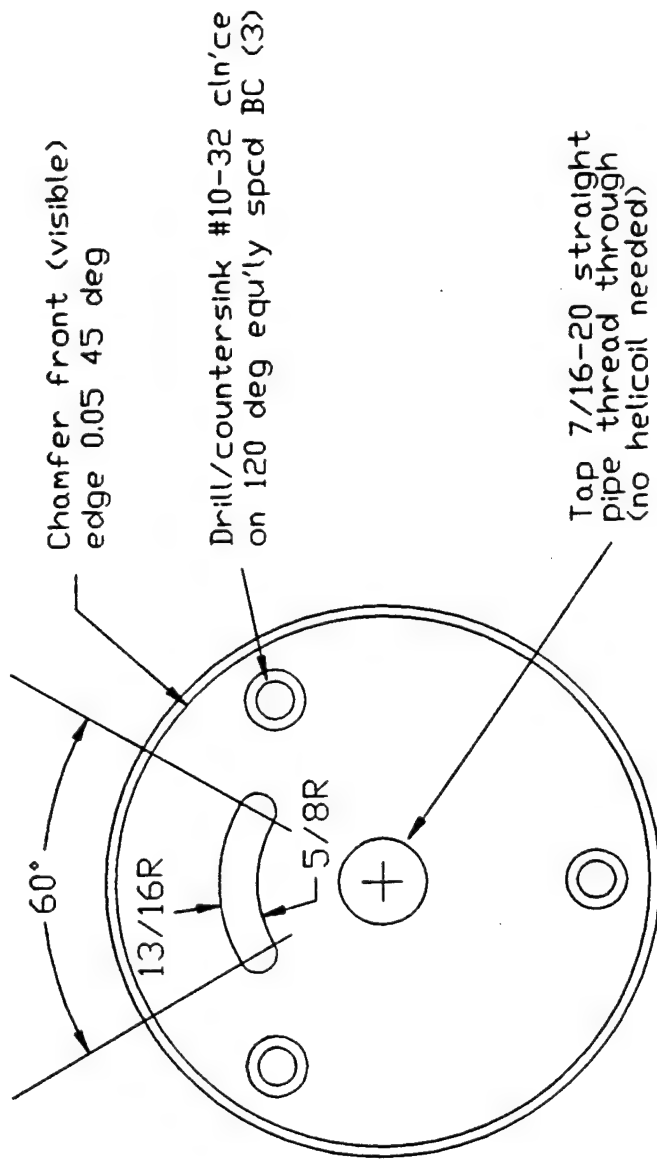








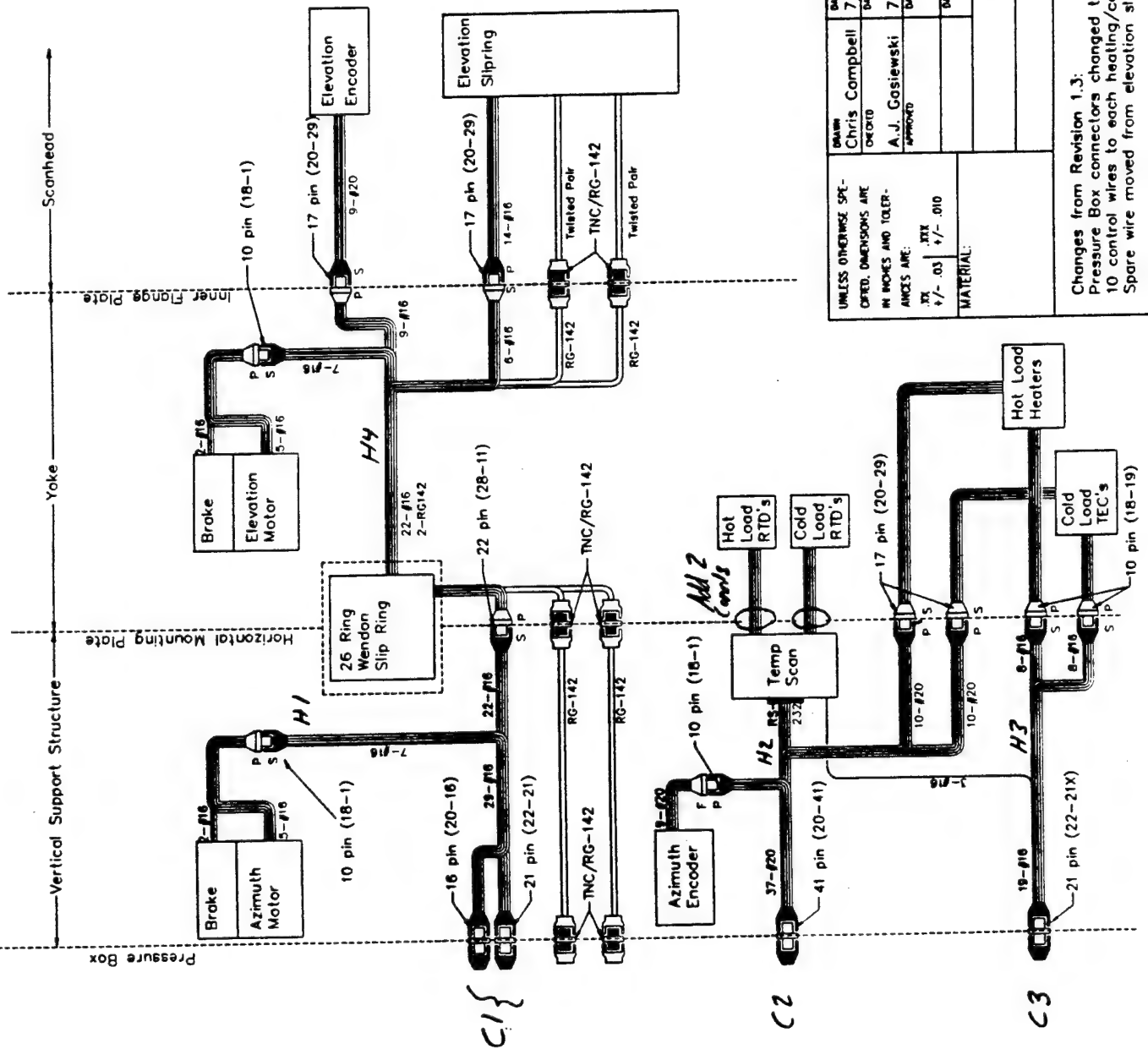
- BC diameter ?  
- O.D. ?



UNLESS OTHERWISE SPEC- IFIED, DIMENSIONS ARE IN INCHES AND TOL- ERANCES ARE: X.X +/- .XX     DATE X.XX +/- .XX     DATE X.XXX +/- .0XX	MATERIAL:  2024 Al  0.25 thick	ISSUED	DATE	Georgia Institute of Technology			
		A.L. Gasiewski	1/23/96	Elevation Bracket Gas Connector Plate			
		DESIGNED	DATE				
		A.J. Gasiewski	1/23/96				
		DRAWN	DATE				
1 pc req'd				Drawing #6	Revision 1.4		
				SCALE	SHEET 2		

Pressurized

Unpressurized



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:		DATE	7/25/95
XX	±.03	DATE	7/11/95
XX	±.010	DATE	
MATERIAL:		DATE	
DESIGN	Chris Campbell	DATE	7/25/95
DRAWN	A. J. Gosiowski	DATE	7/11/95
APPROVED		DATE	
Georgia Institute of Technology		SCALE	Revision 1.4
PSR-2 Electrical Wiring Diagram		Drawing #7	SHEET

Changes from Revision 1.3:  
 Pressure Box connectors changed to accommodate NASA feedthrough availability  
 10 control wires to each heating/cooling load instead of 12  
 Spare wire moved from elevation slipring to elevation encoder

## **PSR Electrical Connectors**

Chris Campbell  
9/20/95

Nearly a hundred different power and instrumentation lines will need to be routed from the aircraft cabin equipment to the scanhead of the PSR. This will involve passing the connections through three boundaries: the pressure box, the horizontal mounting plate, and the inner flange plate. This document does not currently address the wiring outside the pressure box (routing from the scanhead installation to the cabin rack installation) nor the wiring physically inside the scanhead drum (beyond the elevation slipring).

All connections, with the exceptions of the coaxial signal lines and the pressure box feedthrough connections, are of Amphenol "plug-and-receptacle" type. When a "plug" is referred to, this means Amphenol Series 97-3106A, with the indicated insert. When a "receptacle" is referred to, this means Amphenol Series 97-3100A, with the indicated insert. This receptacle is physically anchored to the PSR, to a specified plate or other structure. At each plug and receptacle a cable clamp will be needed.

The wiring will be Mil-Spec M22759. For white, teflon-coated, stranded wire, this means M22759/16-16-9 for 16 gauge wire and M22759/16-20-9 for 20 gauge wire. The wire bundles will be sleeved by braided polyester sleeving, such as Alpha GRP-120.

Refer to Drawing #7, "PSR-2 Electrical Wiring Diagram", for a graphical view of the connections discussed below.

The first boundary is the **pressure box**. This provides the boundary between the pressurized aircraft cabin and the unpressurized PSR body. It provides no structural support for the PSR. Six (6) connectors will be required at this boundary. Each of the first four connectors is a three-piece design: a double-jack bulkhead feed-through (MS3119E), and a screw on plug for either side of the boundary (MS3476W). Since each bulkhead feed-through is installed in the pressure box, these are specified to NASA, who then install the items on the pressure box. The connectors required:

- A 16-pin 16-gauge feed-through, insert type 20-16. These wires then join with the wires from the connector below. This particular wire bundle was specifically split up into two connections to accommodate NASA feed-through availability.
- A 21-pin 16-gauge feed-through, insert type 22-21. Having joined with the wires from the above connector, these wires (currently only 29 of the 37 total pins) then separate into a 7-wire bundle for the azimuth motor and brake, and a 22-wire bundle for the azimuth slipring feed-through.
- A 41-pin 20-gauge feed-through, insert type 20-41. These wires (currently only 37 of the 41 pins) then separate into a 9-wire bundle for the azimuth encoder, a 10-wire bundle for the hot load heater control, a 10-wire bundle for the cold load TEC control, and an 8-wire bundle for the RS-232 data from the thermocouples.

- A 21-pin 16-gauge feed-through, insert type 22-21X. These wires (currently only 19 of the 21 pins) then separate into two 8-wire bundles for the hot load heater power and the cold load TEC power, and 3 power wires for the temp. scanner and scanner box heater. The "X" in the insert type designates a non-standard key rotation on the connector, to prevent inadvertant connection with the other 22-21 connection.

The remaining two connections at the pressure box are TNC connections for the RG-142 coaxial cables carrying the video and Ethernet signals from the scanhead. These are also three-piece designs. The feedthrough has been specified by NASA as Amp #221500-1, for 50 ohm coax.

The exact same connectors specified above will be required for the cabin rack boundary. That is, four M3119/3476 combinations for the signal/power bundles and two TNC combinations for the Ethernet and video signals will be needed to pass the wiring into the rack-mounted equipment.

The second boundary is the **horizontal mounting plate**. This is the boundary between the vertical support structure area and the yoke area. The plate provides structural support for the PSR scanhead, yoke assembly, and elevation motor, which are all suspended from this plate. Nine (9) connectors will be required at this boundary. Seven (7) of these connectors are Amphenol plug-and-receptacle type, the exceptions being the two TNC coaxial feedthroughs.

- A 22-pin 16-gauge connector, insert type 28-11. These wires (currently all 22 of 22 pins, including one spare) then run directly to the non-rotating portion of the azimuthal slipring. The plug (aircraft side) contains a female insert, and the receptacle (slipring side) contains a male insert, to prevent accidental shorting or grounding of the power feeds coming from the aircraft.

The maximum currents on each wire are as follows:

<u>Connection</u>	<u># Lines</u>	<u>Current / Line</u>
El. Motor	5	13 A
El. Brake	2	Low
Encoder	8	Low
Power	2	10 A
Ground	2	10 A
IRIG-B	2	Low
[spare]	1	-

- The two coaxial lines are routed through the plate via the TNC feedthroughs as at the pressure box boundary. These wires then run directly to the non-rotating portion of the azimuth slipring.

- A 10-pin 16-gauge connector, Amphenol insert type 18-1. These wires (currently 7 of 10 pins) then separate into a 5-wire bundle for the azimuth motor and a 2-wire bundle for the motor brake. The plug (aircraft side) contains a female insert, and the receptacle (motor side) contains a male insert, to prevent accidental shorting or grounding of the power feeds coming from the aircraft. While this connector will not actually be mounted in the horizontal mounting plate (but instead to an angle bracket on the motor), it is grouped here with this boundary set for clarity.

The maximum currents on each wire are as follows:

<u>Connection</u>	<u># Lines</u>	<u>Current / Line</u>
Az. Motor	5	13 A
Az. Brake	2	Low

- Another 10-pin 16-gauge connector, insert type 18-1. These wires (currently 9 of 10 pins) then run directly to the azimuth encoder, via 20-gauge wiring. The plug (aircraft side) contains a male insert, and the receptacle (encoder side) contains a female insert. Note that the plug side, coming from the aircraft, has 16-gauge wire running to it, but the receptacle has 20-gauge wire running from it. While this connector will not actually be mounted in the horizontal mounting plate, it is grouped here with this boundary set for clarity, as the motor connector above.
- Two identical 10-pin 16-gauge connectors, insert type 18-19. These wires (currently 8 of 10 pins, each) then run directly to the hot load heaters and the cold load thermoelectric coolers (TEC's), carrying AC power to these units. Each of the two sets of heaters could draw as much as 10 Amps of 120 VAC power for as long as 20 minutes, so the current is split up into 4 wires for each power line. For each connector pair, the plug (aircraft side) contains a female insert, and the receptacle (heater/TEC side) contains a male insert. The cold load connection is for future use in the event that cooling of the load seems appropriate.
- Two identical 17-pin 20-gauge connectors, insert type 20-29. For each connector, these wires (currently only 10 of 17 pins) then split into a 4-wire bundle for the heater/cooler power relay signals, and an 6-wire bundle for the heater/cooler RTD data. For each connector, the plug (aircraft side) contains a male insert, and the receptacle (heater/cooler side) contains a female insert.
- The remaining 8 wires coming from the pressure box boundary run to the temperature scanner, terminating in an RS-232 connection. The hot and cold load RTD signals run directly from the thermocouples to the temperature scanner, without any intermediate connection at the horizontal mounting plate penetration; instead, the wire bundles will simply run through a hole drilled in the

plate. This is to minimize signal contamination at any connectors, which must be done to achieve the accuracy required from this temperature data.

The third boundary is the **inner flange plate**. This is the boundary between the yoke area and the scanhead area. The plate provides structural support for the PSR scanhead, which is suspended from this plate. Five (5) connectors will be required at this boundary. Three (3) of these connectors are Amphenol plug-and-receptacle type, the exceptions being the two TNC coaxial feedthroughs.

- A 17-pin 16-gauge connector, insert type 20-29. These wires (currently 9 of 17 pins) then run directly to the elevation encoder, via 20-gauge wiring. The receptacle (aircraft side) contains a male insert, and the plug (encoder side) contains a female insert. Note that the receptacle side, coming from the aircraft, has 16-gauge wire running to it, but the plug has 20-gauge wire running from it. This connector was chosen to be symmetrical with the elevation sliping connector below, and therefore has eight spare pins.
- Another 17-pin 16-gauge connector, insert type 20-29. These wires (currently 14 of 17 pins) then run directly to the non-rotating portion of the elevation sliping. The receptacle (aircraft side) contains a female insert, and the plug (sliping side) contains a male insert, to prevent accidental shorting or grounding of the power feeds coming from the aircraft. Note that there are only six 16-gauge wires running to the receptacle on the aircraft side. Four of these wires carry 28V DC power to the scanhead, and their max current loads (10 A each) exceed the sliping capability (5 A each). To get around this, each of the power lines is "tripled-up" at the plug (sliping side) to split up the current loads onto three wires for each power line.

<u>Connection</u>	<u>— Aircraft Side —</u>		<u>— Sliping Side —</u>	
	<u># Lines</u>	<u>Current / Line</u>	<u># Lines</u>	<u>Current / Line</u>
Power	2	10 A	6	3.3 A
Ground	2	10 A	6	3.3 A
IRIG-B	2	Low	2	Low

- The two coaxial lines are routed through the plate via the TNC feedthroughs as above. These wires then run directly to the non-rotating portion of the azimuth sliping.
- A 10-pin 16-gauge connector, insert type 18-1. These wires (currently 7 of 10 pins) then separate into a 5-wire bundle for the elevation motor and a 2-wire bundle for the motor brake. The plug (aircraft side) contains a female insert, and the receptacle (motor side) contains a male insert, to prevent accidental shorting or grounding of the power feeds coming from the aircraft. While this connector will not actually be mounted in the inner flange plate (but instead to an angle bracket on the motor), it is grouped here with this boundary set for clarity.



## Connector Summary

For the rack-mount boundary:

<u>Connector Purpose</u>	<u>Feedthrough</u>		<u>Plugs (2 each)</u>	
	<u>Part #</u>	<u>Inserts</u>	<u>Part #</u>	<u>Inserts</u>
Scanhead wiring	MS-3119E	20-16C	MS-3476W	20-16S/P
	MS-3119E	22-21C	MS-3476W	22-21S/P
Cal. load data	MS-3119E	20-41C	MS-3476W	20-41S/P
Cal. load power	MS-3119E	22-21C -X	MS-3476W	22-21S/P -X

For the pressure box boundary:

<u>Connector Purpose</u>	<u>Feedthrough</u>		<u>Plugs (2 each)</u>	
	<u>Part #</u>	<u>Inserts</u>	<u>Part #</u>	<u>Inserts</u>
Scanhead wiring	MS-3119E	20-16C	MS-3476W	20-16S/P
	MS-3119E	22-21C	MS-3476W	22-21S/P
Cal. load data	MS-3119E	20-41C	MS-3476W	20-41S/P
Cal. load power	MS-3119E	22-21C -X	MS-3476W	22-21S/P -X

For the horizontal mounting plate boundary:

<u>Connector Purpose</u>	<u>Receptacle side</u>		<u>Plug side</u>	
	<u>Part #</u>	<u>Inserts</u>	<u>Part #</u>	<u>Inserts</u>
Azimuth Slipring	97-3100A	28-11P	97-3106A	28-11S
Azimuth Motor	97-3100A	18-1P	97-3106A	18-1S
Azimuth Encoder	97-3100A	18-1S	97-3106A	18-1P
Hot Load Power	97-3100A	18-19P	97-3106A	18-19S
Cold Load Power	97-3100A	18-19P	97-3106A	18-19S
Hot Load Control	97-3100A	20-29S	97-3106A	20-29P
Cold Load Control	97-3100A	20-29S	97-3106A	20-29P

For the inner flange plate boundary:

<u>Connector Purpose</u>	<u>Receptacle side</u>		<u>Plug side</u>	
	<u>Part #</u>	<u>Inserts</u>	<u>Part #</u>	<u>Inserts</u>
Elevation Encoder	97-3100A	20-29P	97-3106A	20-29S
Elevation Slipring	97-3100A	20-29S	97-3106A	20-29P
Elevation Motor	97-3100A	18-1P	97-3106A	18-1S

Insert notation: "P" = "pins" or male; "S" = "socket" or female

**Connector shell dimension information** (see Amphenol catalog for drawings)

Note: These dimensions are for the plug-and-receptacle connections only; these do not apply to the pressure box feedthrough connections. All dimensions in inches.

**Size 28 Connector (1 pair: Azimuth Slipring)**

<u>Receptacle</u>	<u>Panel Cutout Diam.</u>	<u>Flange thickness</u>	<u>Mounting Hole Spacing</u>	<u>&amp; Diameter</u>
97-3100A	1.812	1/8	19/16	0.147

**Size 20 Connectors (4 pairs: Hot Load Control, Cold Load Control, Elevation Slipring, Elevation Encoder)**

<u>Receptacle</u>	<u>Panel Cutout Diam.</u>	<u>Flange thickness</u>	<u>Mounting Hole Spacing</u>	<u>&amp; Diameter</u>
97-3100A	1.312	1/8	15/32	0.120

**Size 18 Connectors (5 pairs: Azimuth Motor, Azimuth Encoder, Hot Load Power, Cold Load Power, Elevation Motor)**

<u>Receptacle</u>	<u>Panel Cutout Diam.</u>	<u>Flange thickness</u>	<u>Mounting Hole Spacing</u>	<u>&amp; Diameter</u>
97-3100A	1.188	1/8	11/16	0.120

The maximum currents on each wire are as follows:

<u>Connection</u>	<u># Lines</u>	<u>Current/Line</u>
El. Motor	5	13 A
El. Brake	2	Low

# Wendon 26-Contact Azimuthal Slip Ring Wiring Code

A.J. Gasiewski  
April 5, 1996

Ring #	Wire Type/Brush Block	Function
1	Teflon (S, top)	Elevation motor drive A (RED)
2	Teflon (L, top)	Elevation motor drive A (BLK)
3	Teflon (S)	Elevation motor drive B (GRN)
4	Teflon (L)	Elevation motor drive B (BLK)
5	Teflon (S)	Elevation motor brake power (WHT)
6	Teflon (L)	Yoke-vert. support chassis ground connection
		Elevation motor shields (3, bare)
		Elevation motor brake return (BLK)
		Elevation optical encoder case ground (GRN)
		and shield drain (WHT)
7	Teflon (S)	Elevation optical encoder A (YEL)
8	Teflon (L)	Elevation optical encoder ~A (WHT/YEL)
9	Teflon (S)	Elevation optical encoder B (BLU)
10	Teflon (L)	Elevation optical encoder ~B (WHT/BLU)
11	Teflon (S)	Elevation optical encoder Z (ORG)
12	Teflon (L)	Elevation optical encoder ~Z (WHT/ORG)
13	Teflon (S)	Elevation optical encoder +5 VDC (RED)
14	Teflon (L)	Elevation optical encoder return (BLK)
15	Teflon (S)	+28 VDC power
16	Teflon (L)	+28 VDC power
17	Teflon (S)	+28 VDC power
18	Teflon (L)	Power return
19	Teflon (S)	Power return
20	Teflon (L)	Power return
21	Teflon (S)	IRIG-B signal
22	Teflon (L)	IRIG-B return
23	COAX center (L)	Video signal
24	COAX shield (L)	Video return
25	COAX center (L)	Ethernet signal
26	COAX shield (L)	Ethernet return

Notes: Rings are numbered starting on top, closest to the azimuthal drive motor.  
Each ring is rated at 15 amps capacity.  
Rings 23-26 are low capacitance.

## Airflight 24-Contact Elevation Slip Ring Wiring Code

A.J. Gasiewski  
January 25, 1996  
(updated April 5, 1996)

Ring #	Color	Function/Description
1	WHT	Ethernet signal (COAX-1 center conductor in drum)
2	BLK	Ethernet return (COAX-1 shield in drum)
3	RED	Video signal (COAX-2 center conductor in drum)
4	GRN	Video return (COAX-2 shield in drum)
5	YEL	IRIG-B signal
6	BLU	IRIG-B return
7	BRN	Drum-yoke chassis ground connection
8	ORG	Drum-yoke chassis ground connection
9	GRY	Power return
10	VIO	Power return
11	BLK/YEL	Power return
12	BLK/BLU	Power return
(gap of one ring thickness)		
13	BLK/RED	Power return
14	BLK/BRN	Power return
15	BLK/GRN	Power return
16	WHT/RED	Power return
17	WHT/GRN	+28 VDC power
18	WHT/YEL	+28 VDC power
19	WHT/BLU	+28 VDC power
20	WHT/BRN	+28 VDC power
21	WHT/ORG	+28 VDC power
22	WHT/GRY	+28 VDC power
23	WHT/VIO	+28 VDC power
24	WHT/BLK	+28 VDC power

Notes: Rings are numbered starting closest to input drive shaft.  
Each ring is rated at 5 amps capacity.

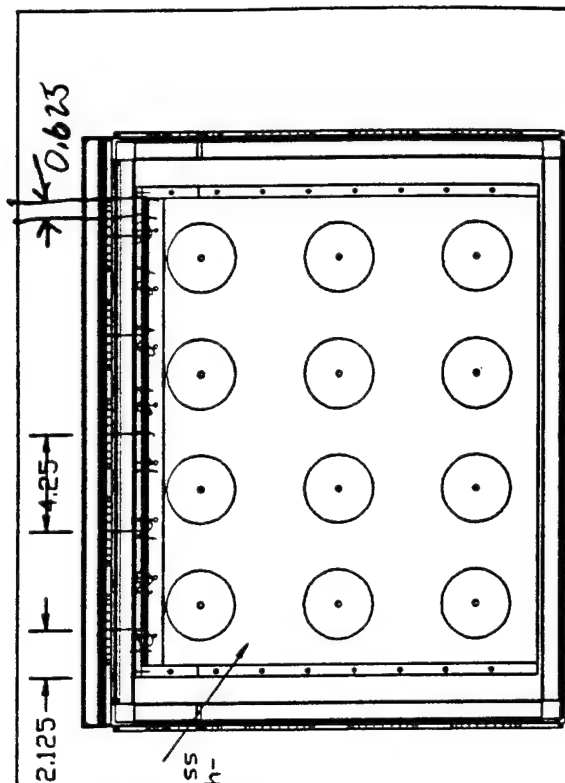
## **Tempscan 9-Pin D-Shell Connector Wiring Code**

**A.J. Gasiewski  
May 6, 1996**

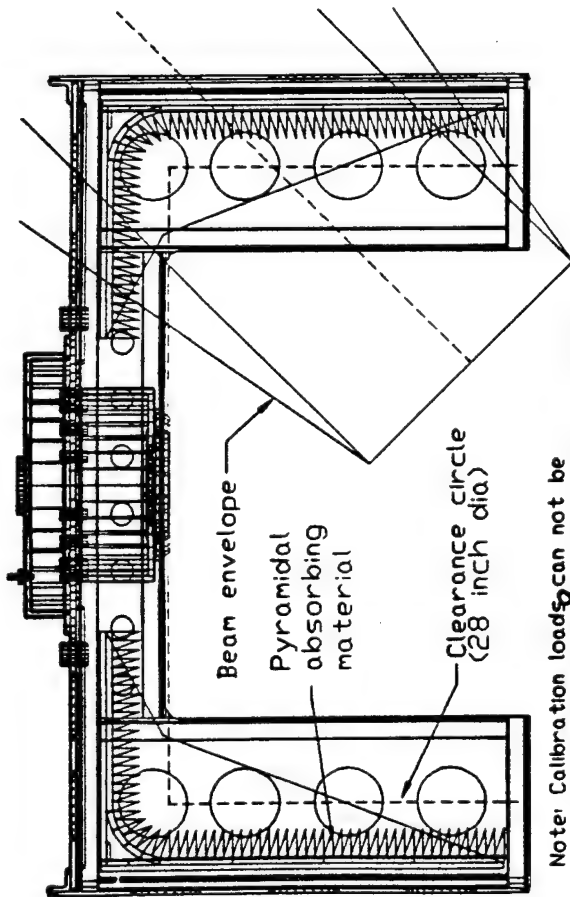
<b>Pin #</b>	<b>Function</b>
1	RTD temperature sensor on Tempscan lid
2	RTD temperature sensor on Tempscan lid
3	RTD shield (connected to Tempscan lid at RTD sensor)
4	N/C
5	120 VAC 60 Hz hot (to hot lead of Tempscan power and to " 1" on heater solid state relay)
6	120 VAC 60 Hz return (to return lead of Tempscan power)
7	Tempscan lid chassis ground (to third lead of Tempscan power, i.e., green lead)
8	N/C
9	Heater current loop control + (to " 3" on heater SS relay)
10	Heater current loop control - (to " 4" on heater SS relay)
11	N/C
12	N/C
13	N/C
14	N/C
15	N/C

**Note: Circuits 5 and 6 connect to Tempscan 120 VAC power in wiring harness.**





See drawing #1 sheet 2 for fiberglass plate attachment details



Note: Calibration loads can not be installed with PSR on aircraft - removal of either outer flange plate or front and back plates is required.

19 #10-32 (rear)

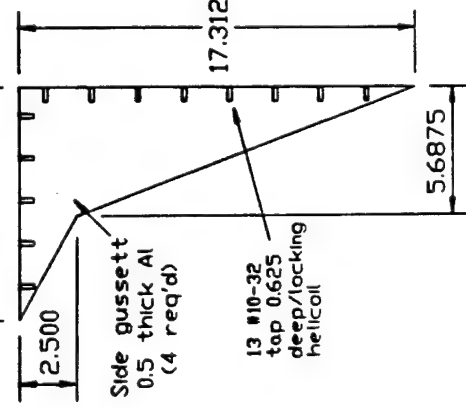
## Components

Cal load thermal plate H 10.25x21.25x1/4 Al (2 req'd)

1.50

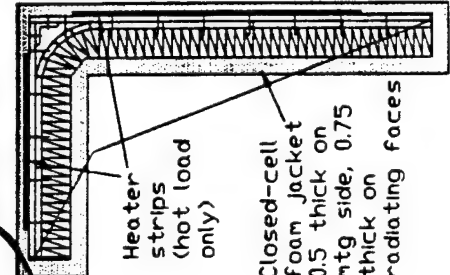
10.250

1.875



Cal load connector bracket 1x13/16x20x25 long angle Al, drill 8 #10-32 clearance (44.6 in) on 2.5 eq'y spc'd centers, each face (2 req'd)

9 #10-32 clearance 44.6 in face to face

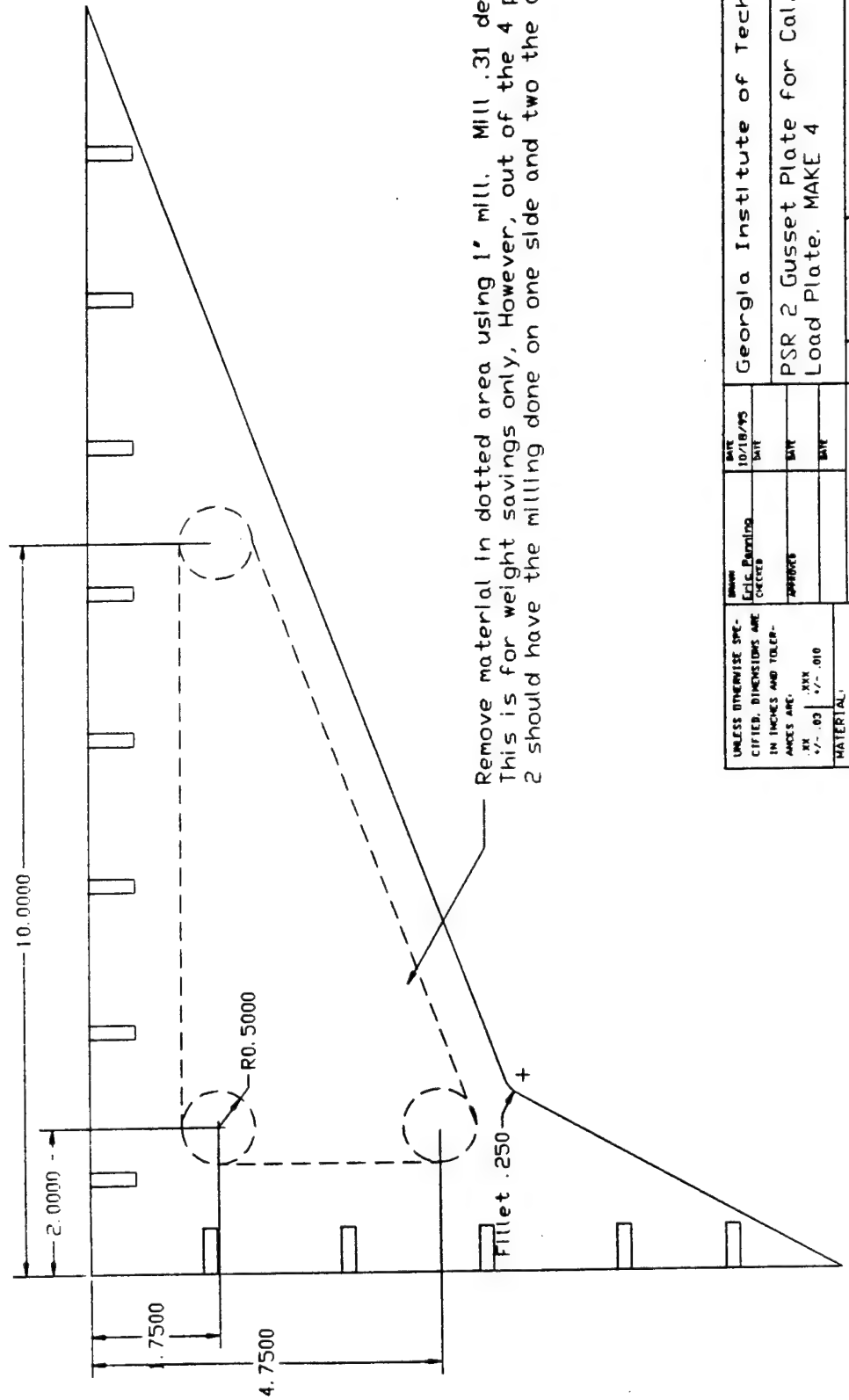


## Attachment

Cal load attachment plates 0.375 fiberglass (2 ea 25.5 x 17.8125 and 11.5 x 23.5 req'd) Fasten to vertical support structure using 1/4-28 hdwre

1/4-28 clearance x 1-dia fiberglass spacers, 12 req'd on side, 10 req'd on top of each load Use MS 21075L4 nut plate on inside of cal load thermal plates

DATE PREPARED BY: A.J. GABRIEL	DATE: 12/20/95	Georgia Institute of Technology
CHECKED BY: [blank]	DATE: [blank]	PROJECT: [blank]
DESIGNED BY: [blank]	DATE: [blank]	PROJECT: [blank]
SCALE: [blank]	Revision 1.0	PSR-2 Calibration Loads
SHEET: [blank]		

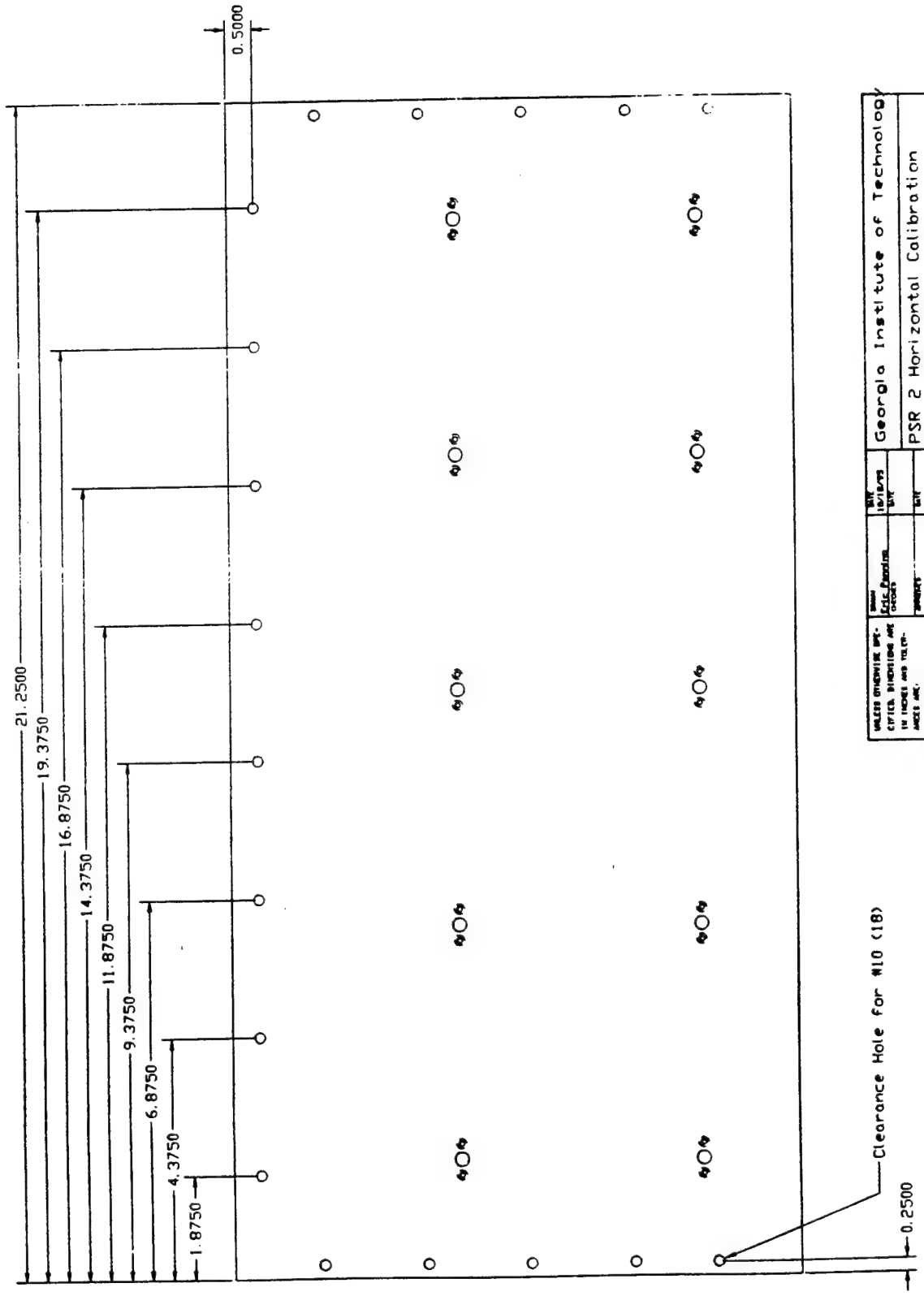


Remove material in dotted area using 1" mill. Mill .31 deep.  
 This is for weight savings only, However, out of the 4 pieces,  
 2 should have the milling done on one side and two the other side.

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE: XX .03 XXX .010 MATERIAL	DATE	10/18/93	Georgia Institute of Technology
	DATE		
	DATE		
	DATE		
PSR 2 Gusset Plate for Cal. Load Plate. MAKE 4			File: Gussetp.dwg
1/2 AI			SHEET 2

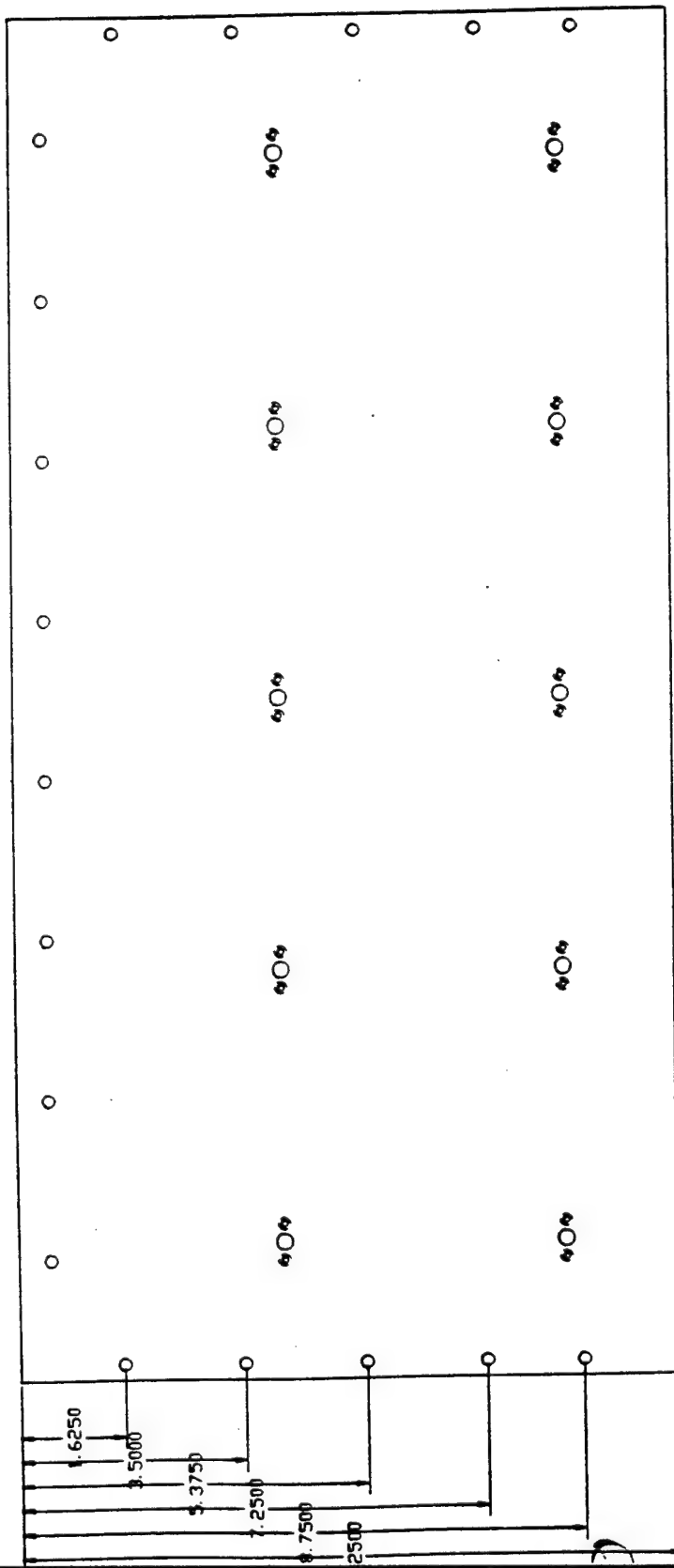




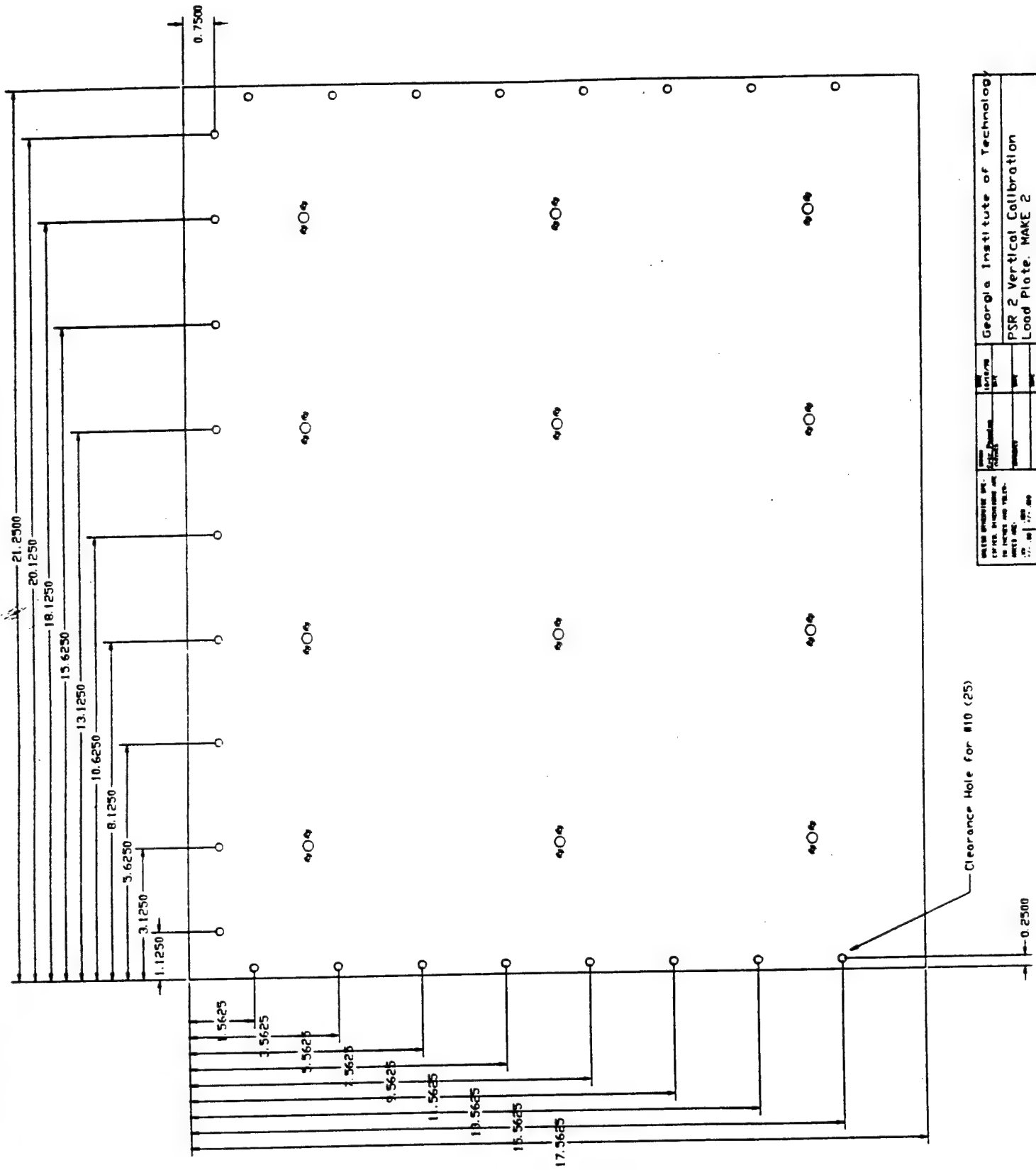


UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:		DATE		Georgia Institute of Technology	
.125	± .005	DATE	DATE	DATE	DATE
.125	± .005	DATE	DATE	DATE	DATE
.125	± .005	DATE	DATE	DATE	DATE
.125	± .005	DATE	DATE	DATE	DATE
MATERIAL		1/4 Al		Drawing #11	
PSR 2 Horizontal Calibration Load Plate. MAKE 2		SHEET 2		SHEET 2	

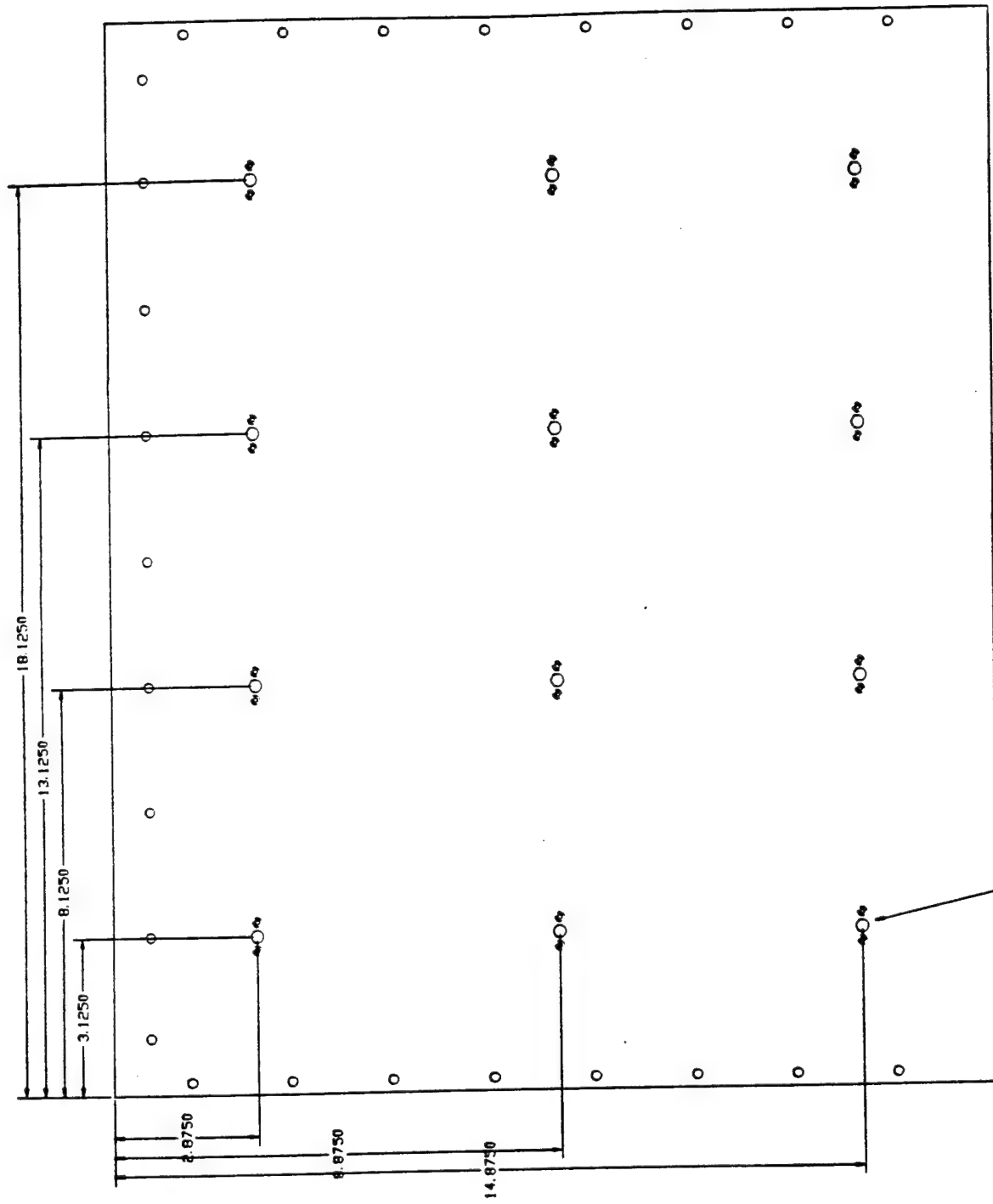




SELECT DRAWING SPEC. CENTS. SHOWING ARE IN INCHES AND FRACTIONS INCHES ARE: 1/16" 1/8" 1/4" 3/8" 1/2" 5/8" 3/4" 7/8" 1"	DATE 10/16-75	Georgia Institute of Technology	
	DATE	PSR 2 Horizontal Calibration	
	PROJECT	Load Plate. MAKE 2	
		Drawing #11	
	MATERIAL: 1/4 Al		SCALE



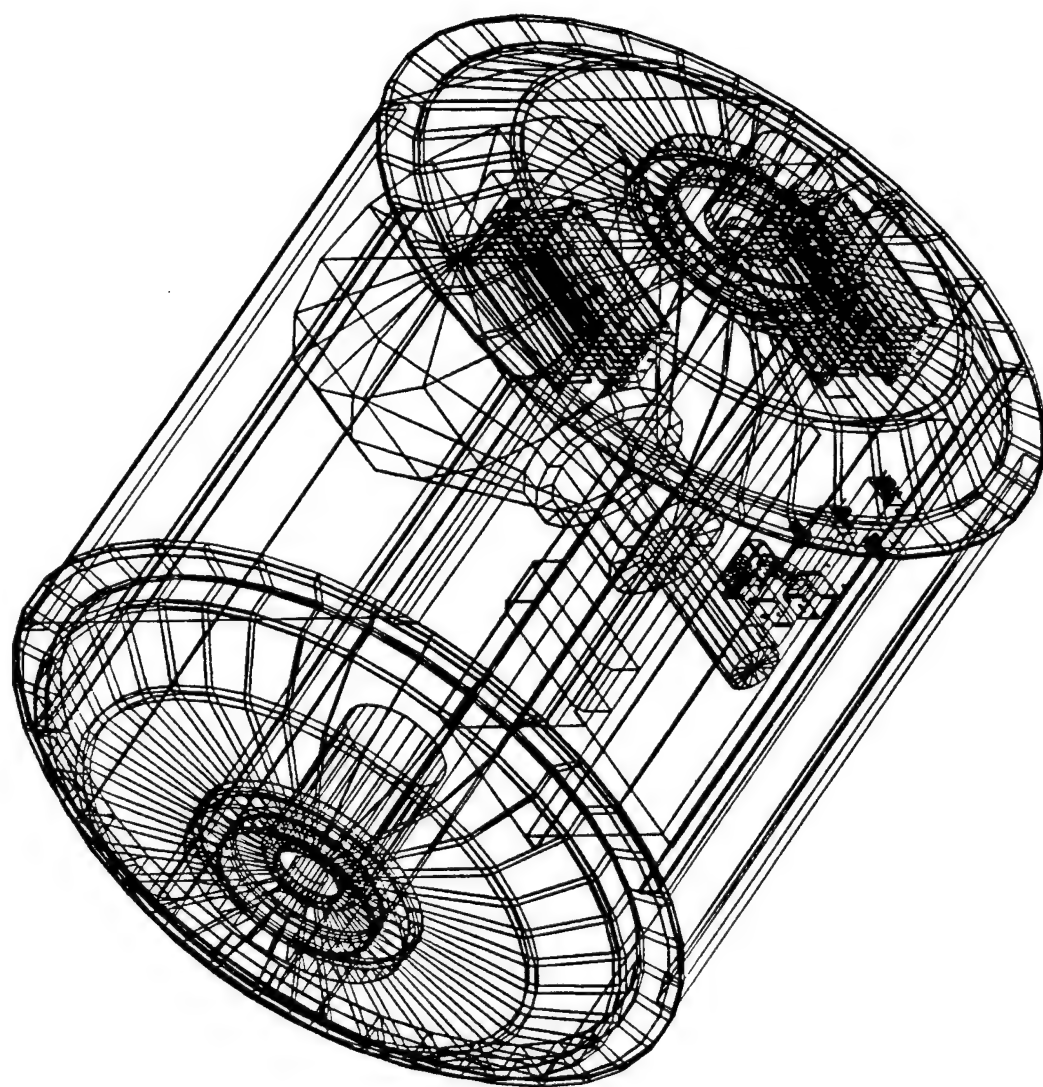
Georgia Institute of Technology	
PSR 2 Vertical Calibration Load Plate, MAKE 2	
Drawing # 11	
1/4 AI	
File: Vertplat.dwg	
SHEET 3	



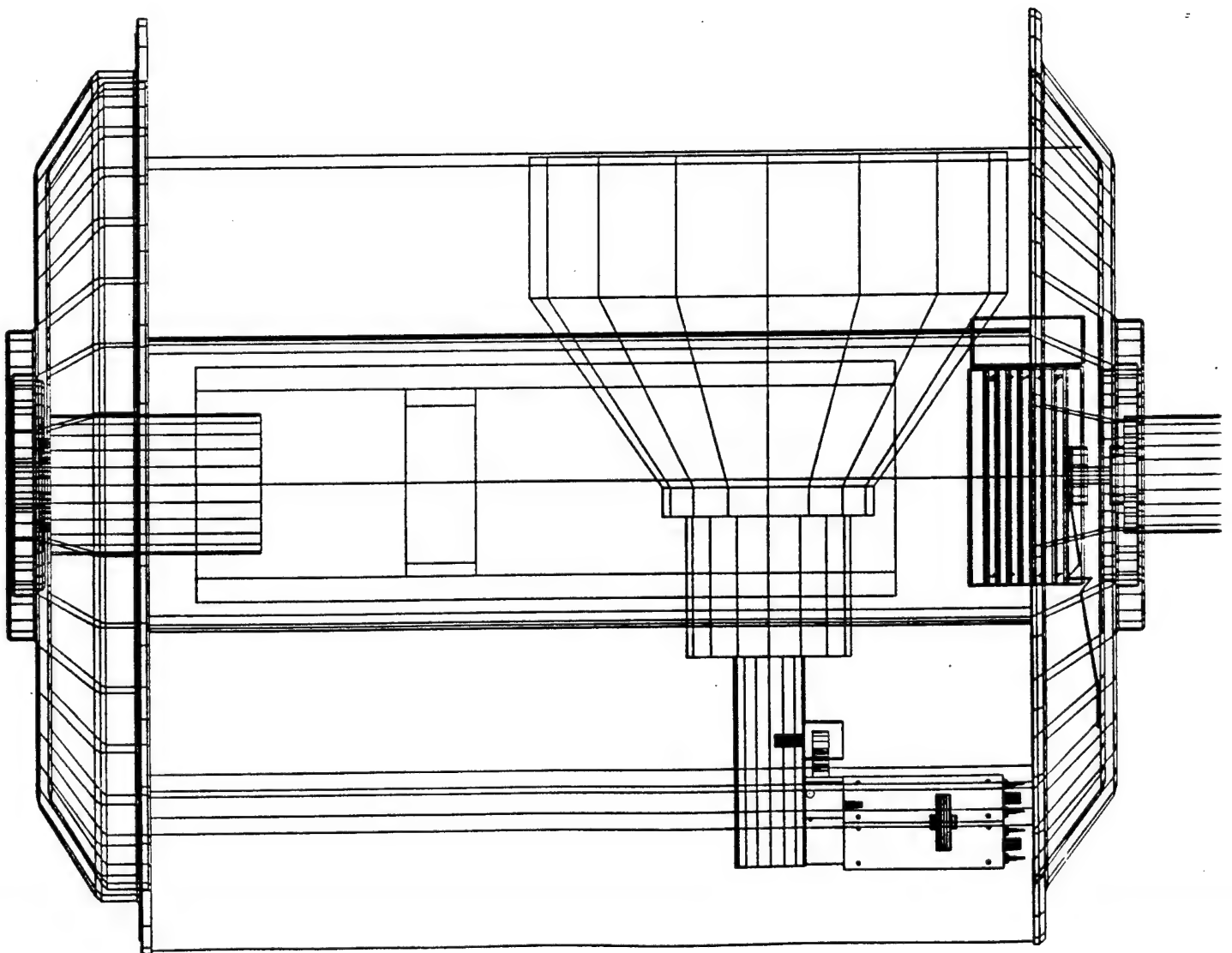
1/4" Clearance Hole with MS21075L4 nut plate on backside. Countersink on topside.

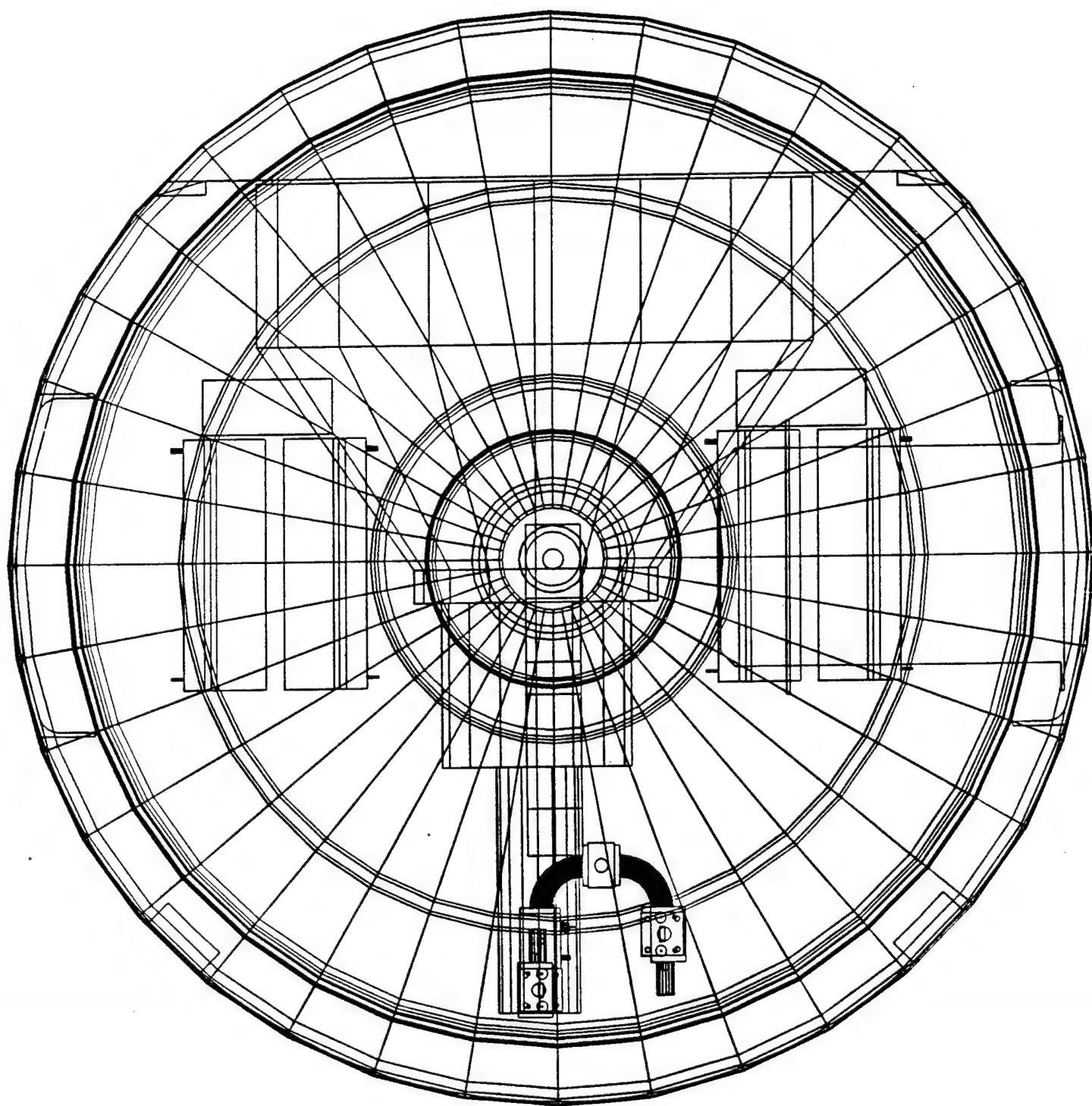
DESIGN APPROVALS: DESIGNED BY: DATE: DRAWN BY: DATE: CHECKED BY: DATE: APPROVED BY: DATE:	Georgia Institute of Technology
PROJECT: PSR 2 Vertical Calibration Load Plate, MAKE 2	
FILE: Vertplat.dwg	
1/4 AI	Sheet 1 of 1

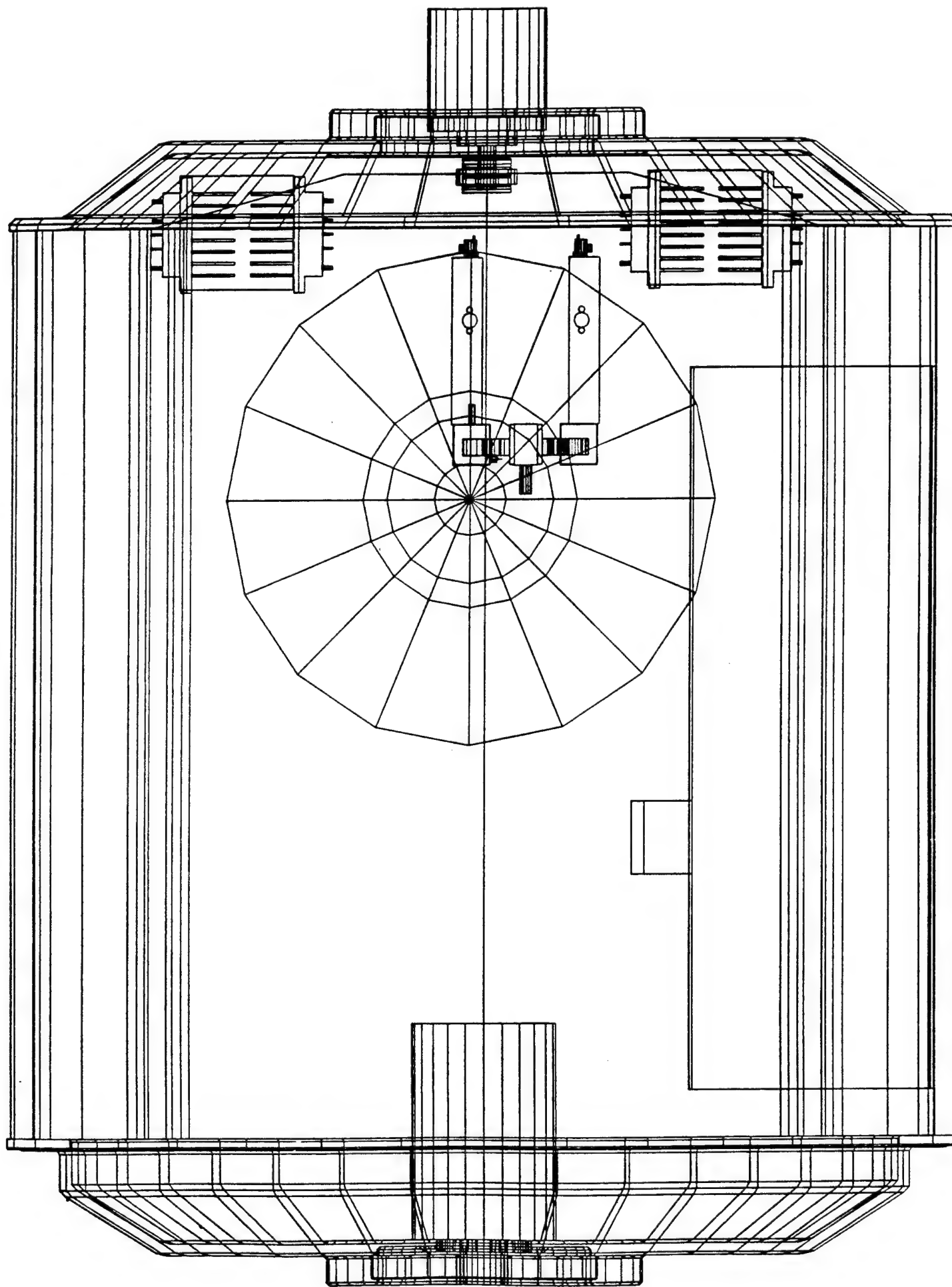








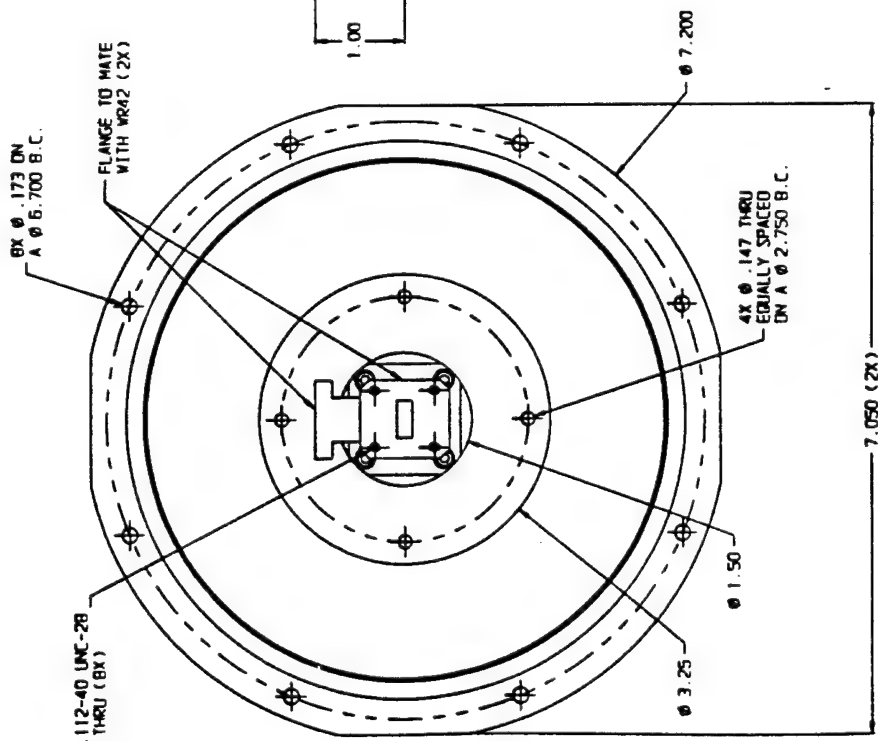
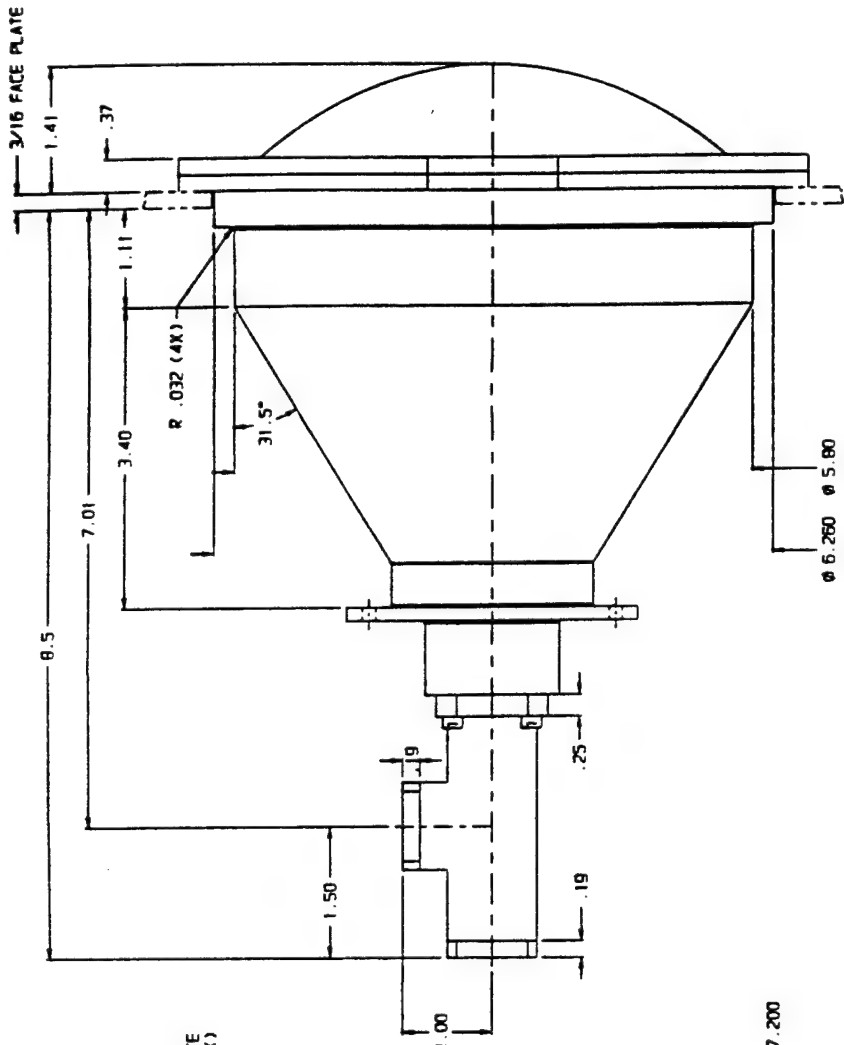






# REVISIONS

REV	DESCRIPTION	DATE	APPROVED



ENGINEERING  
PROTOTYPE

NOTE:  
UNIT CAN BE MOUNTED IN ANY 90° ORIENTATION.

CONTRACT NO.	DATE	REV	DESCRIPTION	APPROVED
CSB 12-05-95	12-05-95	1	18.7 GHz HORN/ LENS	
QJM 12-05-95	12-05-95	1		
KAG 12-05-95	12-05-95	1		
LINEAR TO .001 D10				
FRACTIONAL .001 D10				
ANALOG TO .117				
SCALE 1/1				
SHEET 1 OF 1				

**MICROWAVE ENGINEERING CORPORATION**

1551 Osgood Street, North Andover, MA 01845-1041  
Telephone: (508) 685-2776 Fax: (508) 975-4363

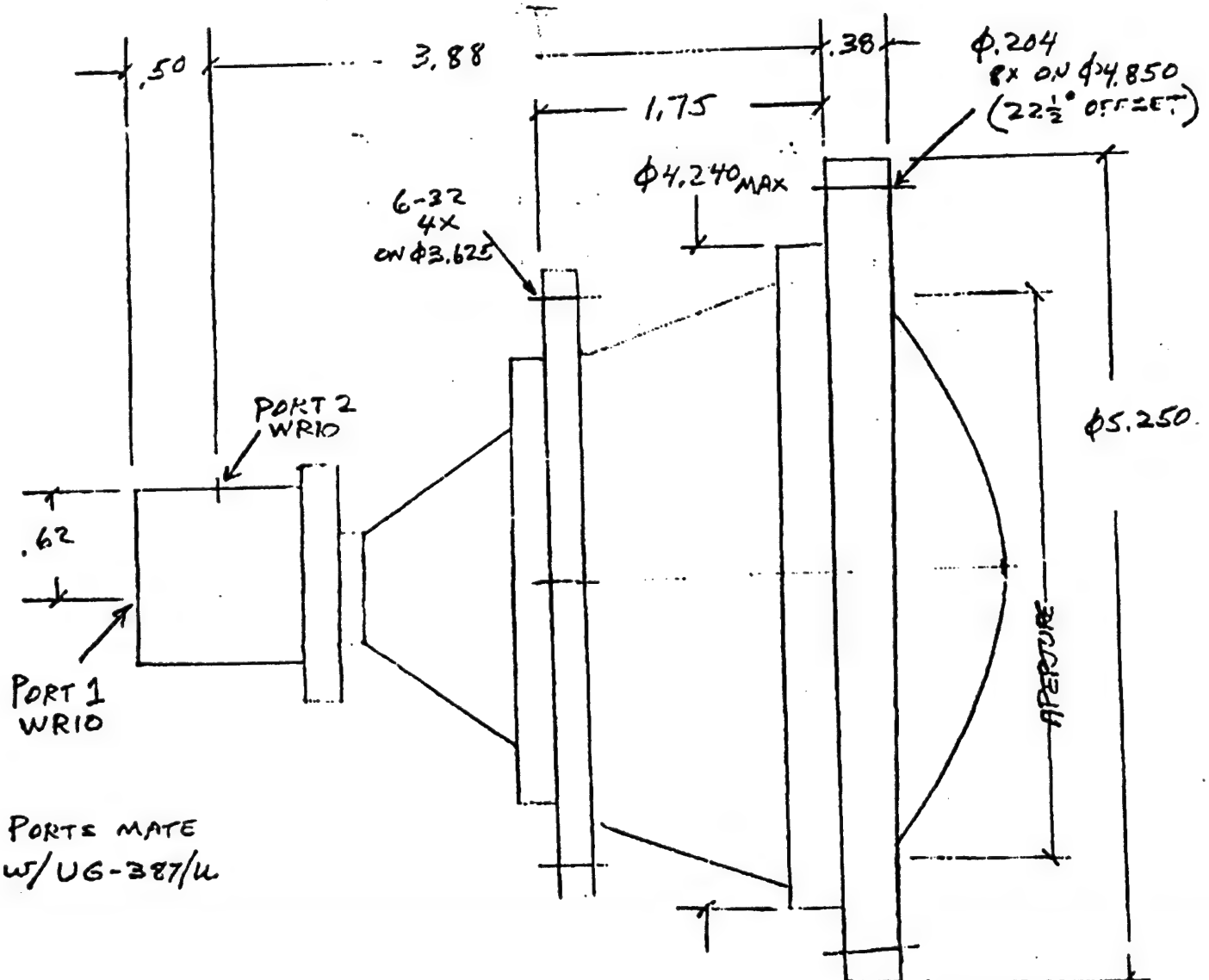
**FAX COVER SHEET**

TO (COMPANY): G.I.T. DATE: 11 APR. 96  
ATTENTION: \_\_\_\_\_ FROM: KEN GREEN  
MAIL STOP: GRAD. STUDENT MAIL BOX  
FAX: 1-404-894-4641 PHONE: \_\_\_\_\_

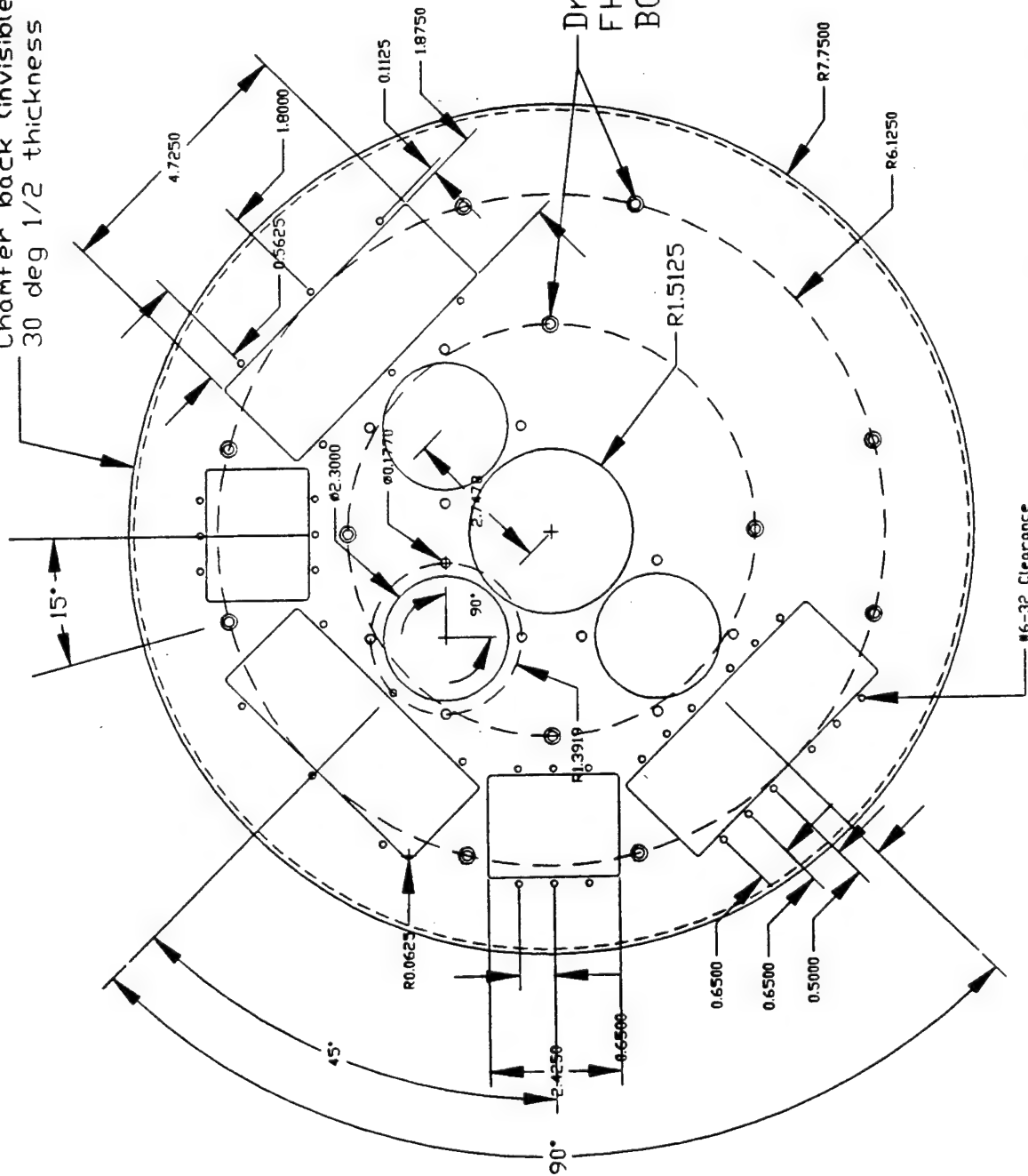
REFERENCE: 89 GHz ANTENNA

PAGE: 1 OF 1

*Jeff, Here is my sketch of the 89 GHz unit,  
which I hope will help you until our  
drawing is ready.*

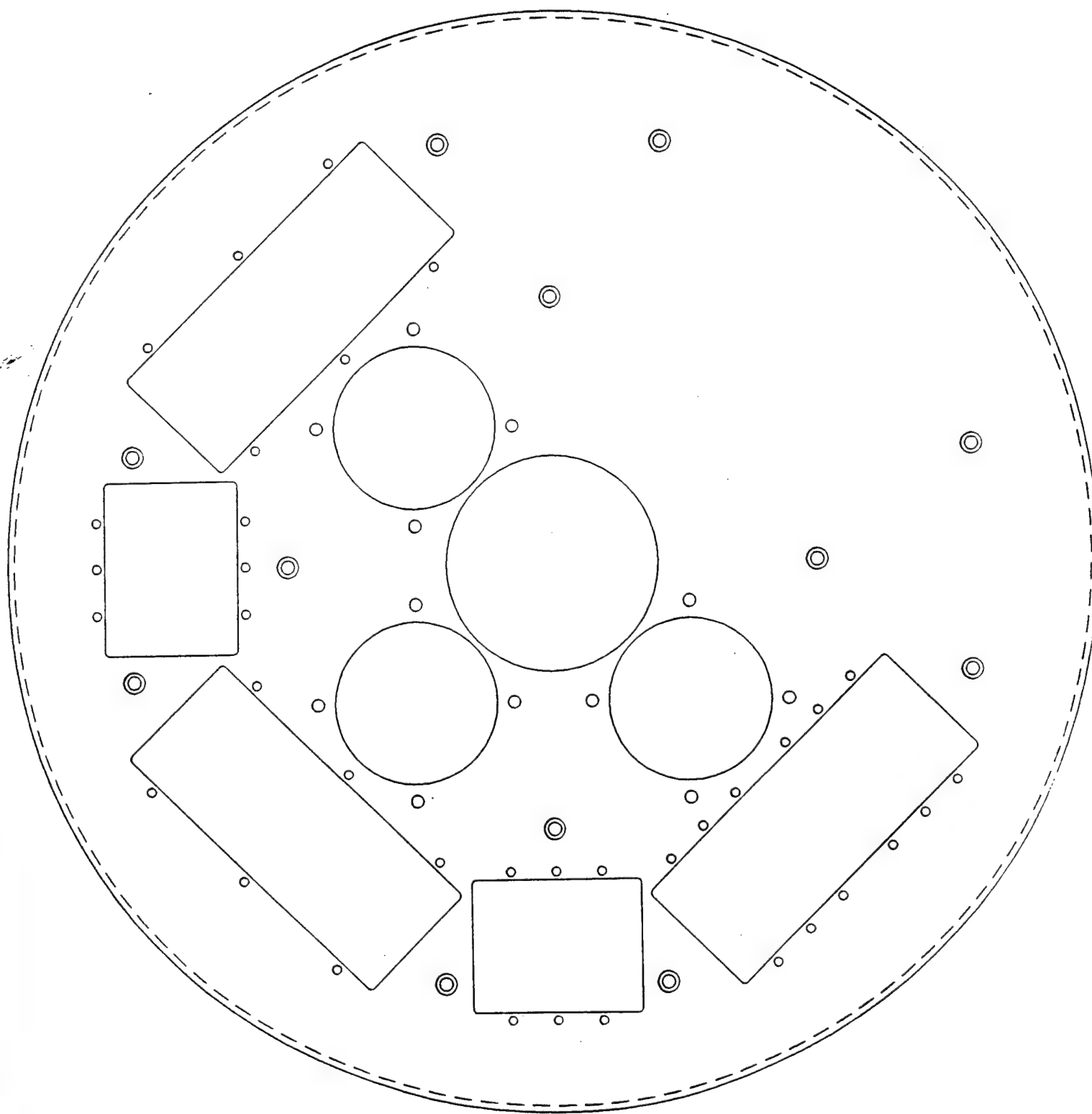


Chamfer back (invisible) edge  
30 deg 1/2 thickness of plate

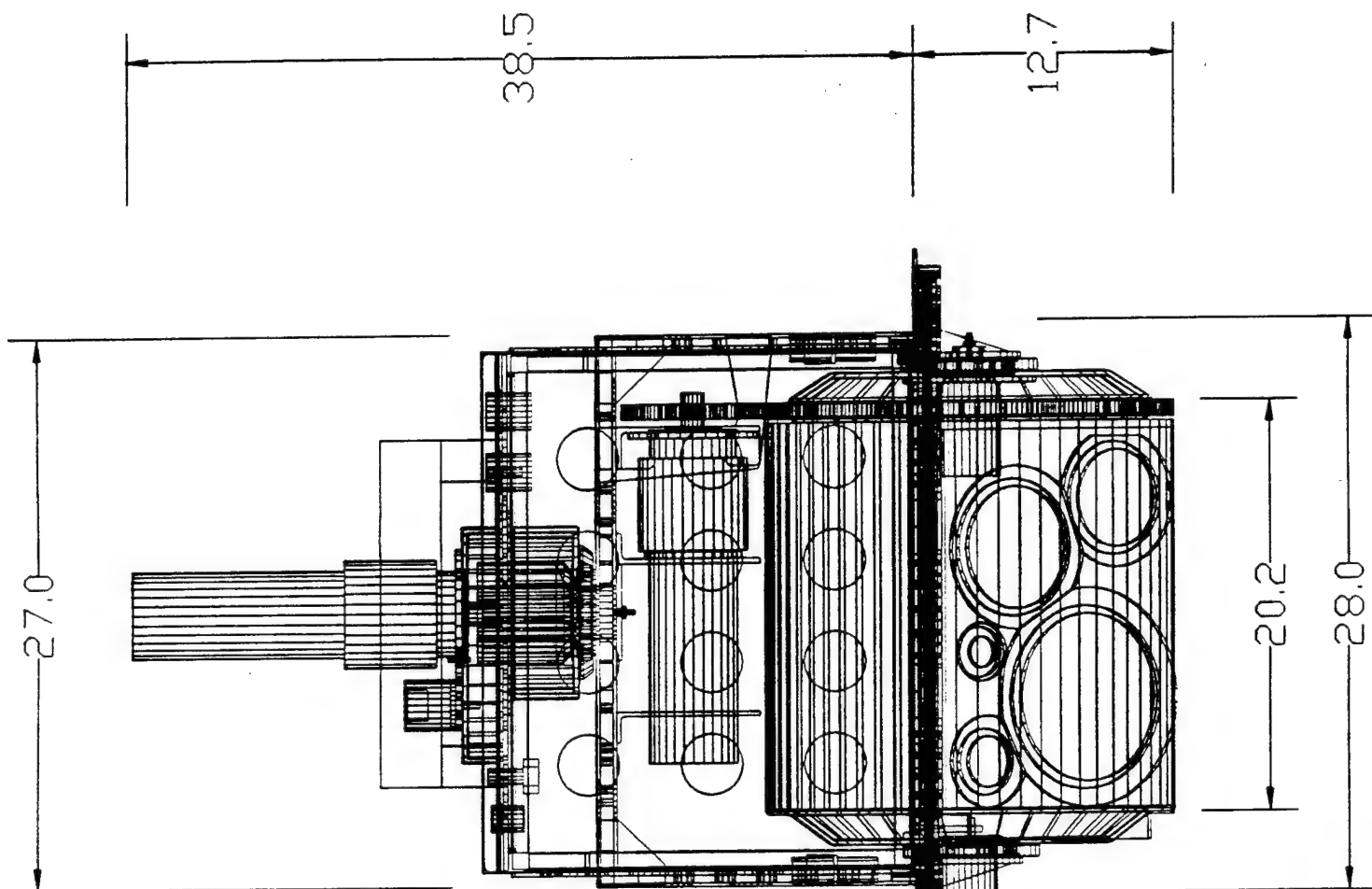


Note: #10-32 countersinks and edge chamfer are on opposite sides.

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE: XX +/- .03 XXX +/- .010	DATE	2/21/96	Georgia Institute of Technology
	DESIGNER	A.J. GOSIOWSKI	
MATERIAL: 6061 Al 3/16 thick	DATE		Power Supply Plate
	APPROVED		
DATE		1 pc req'd	Drawing #12 Revision 1.1
DATE			SCALE
			SHEET 3



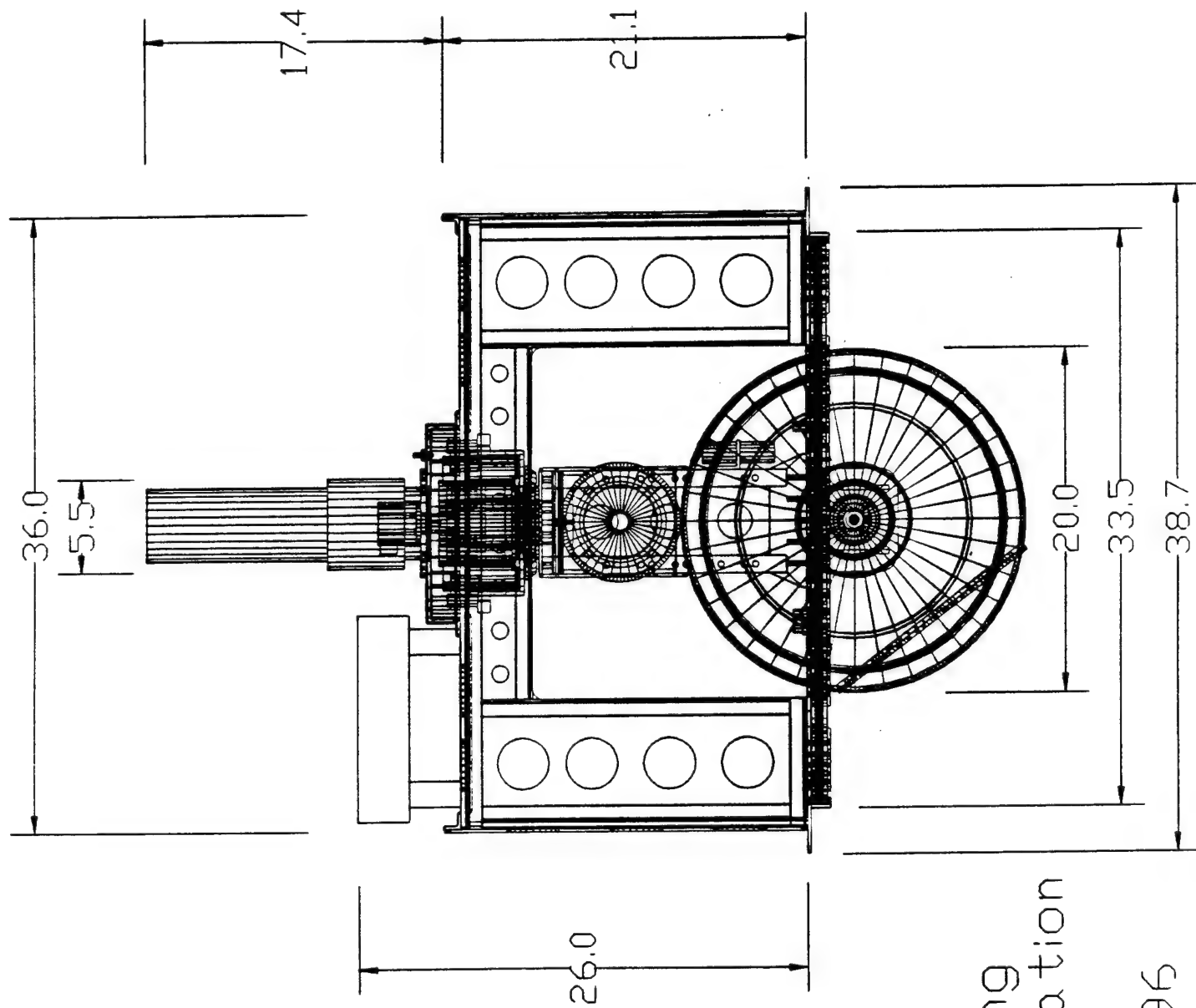




Mounting  
Plane

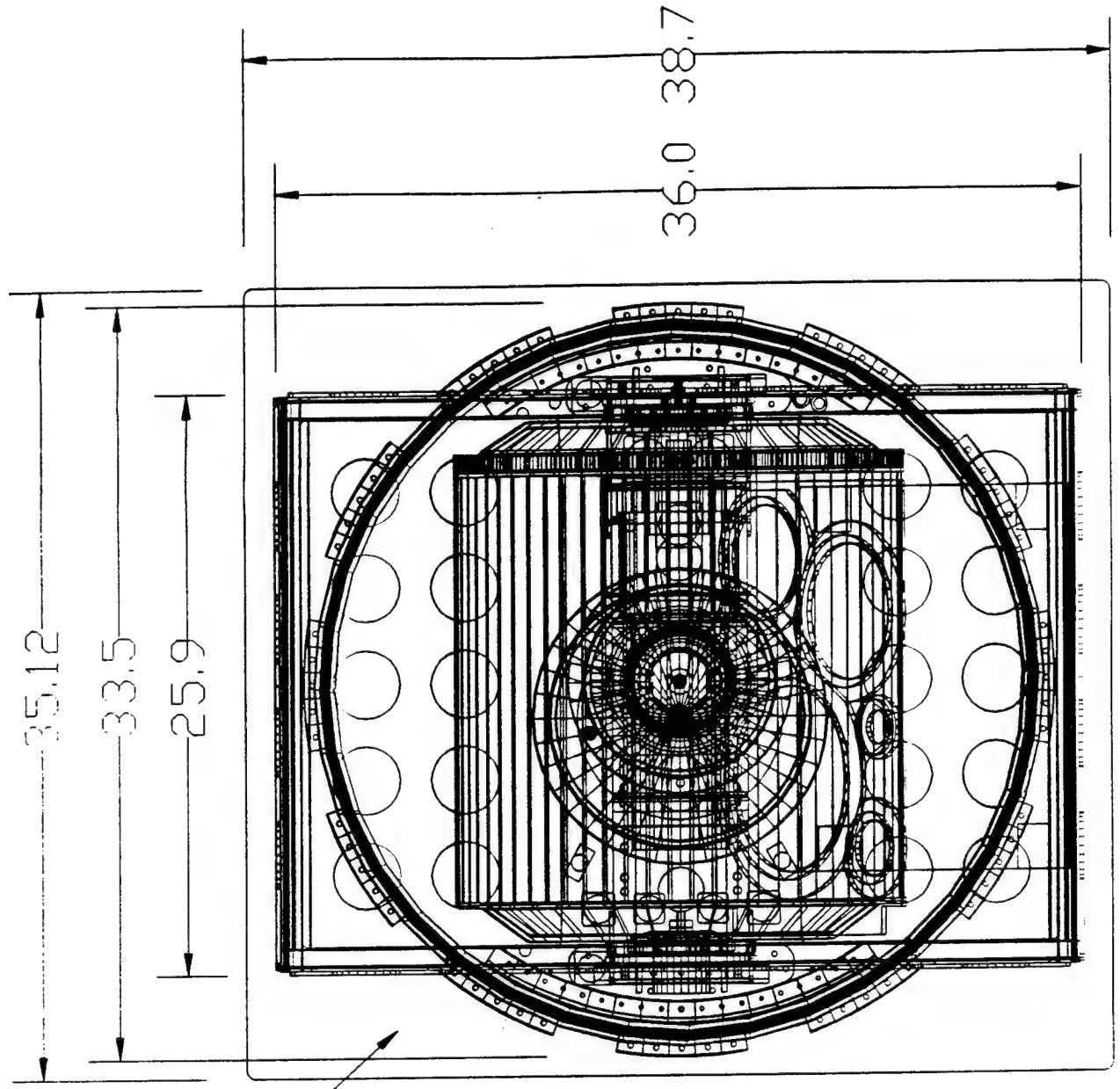
PSR-2  
Dimensions  
for Mounting  
and Integration

AJG 3/29/96



PSR-2  
Dimensions  
for Mounting  
and Integration

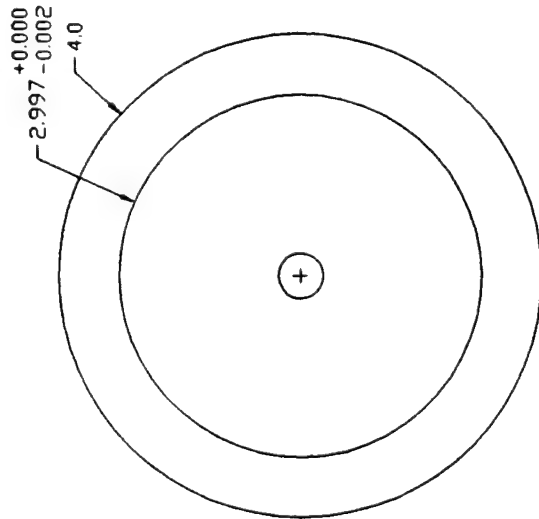
AJG 3/29/96



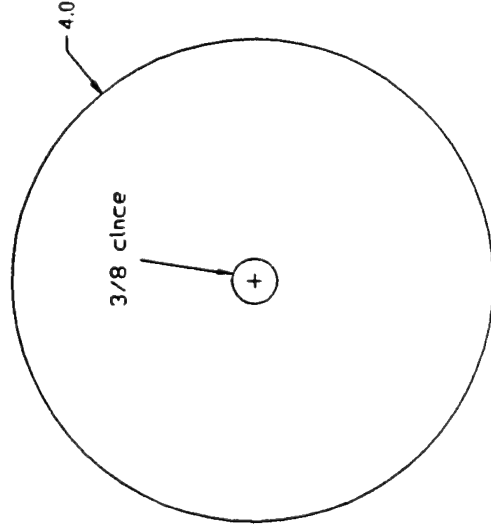
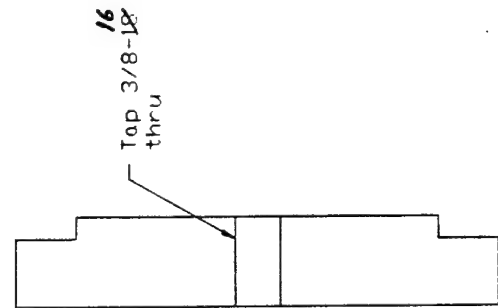
Mounting  
Plane

PSR-2  
Dimensions  
for Mounting  
and Integration

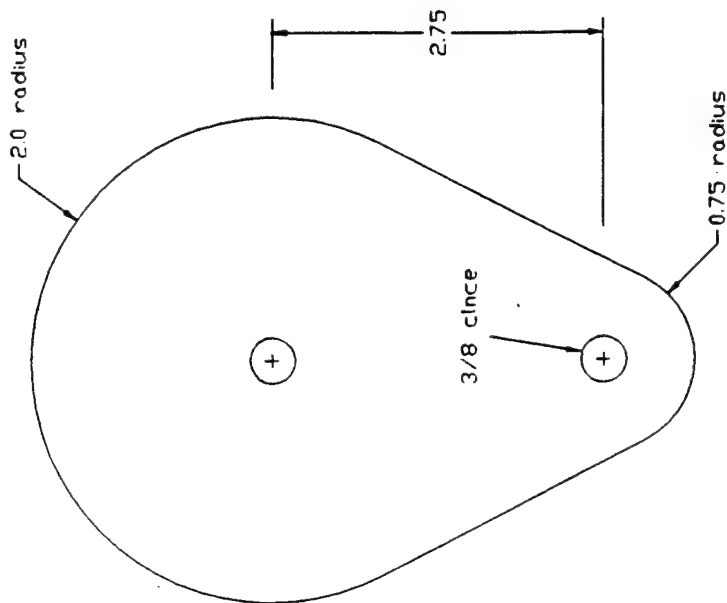
AJG 3/29/96



(1) Center Disk: use 3/4" stock



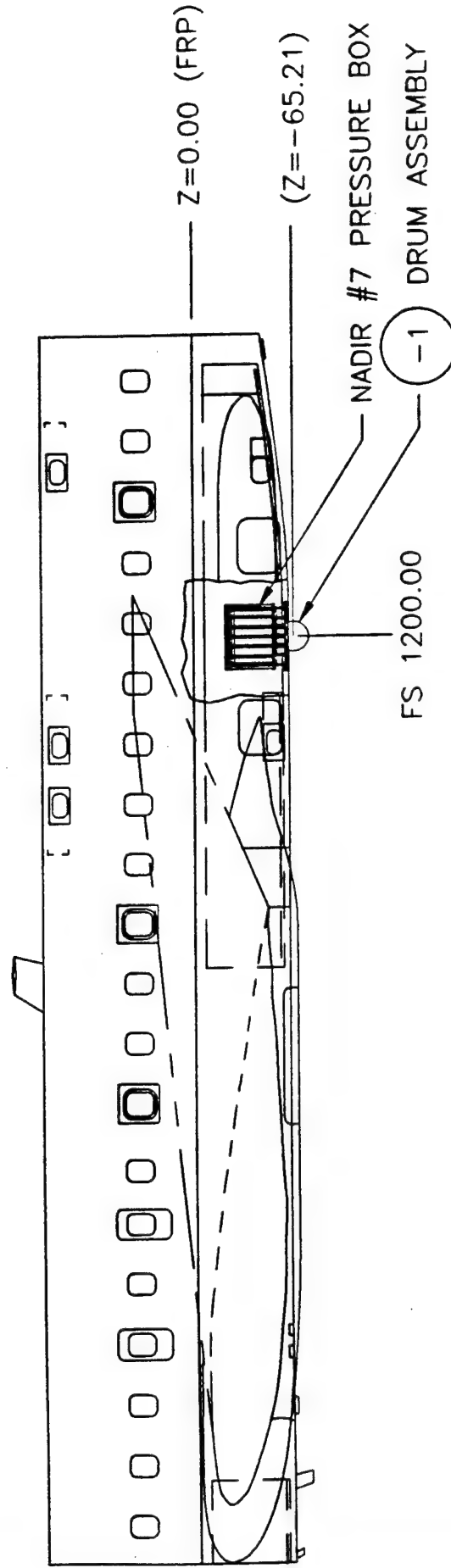
(2) Inner Disk: use 1/4" stock



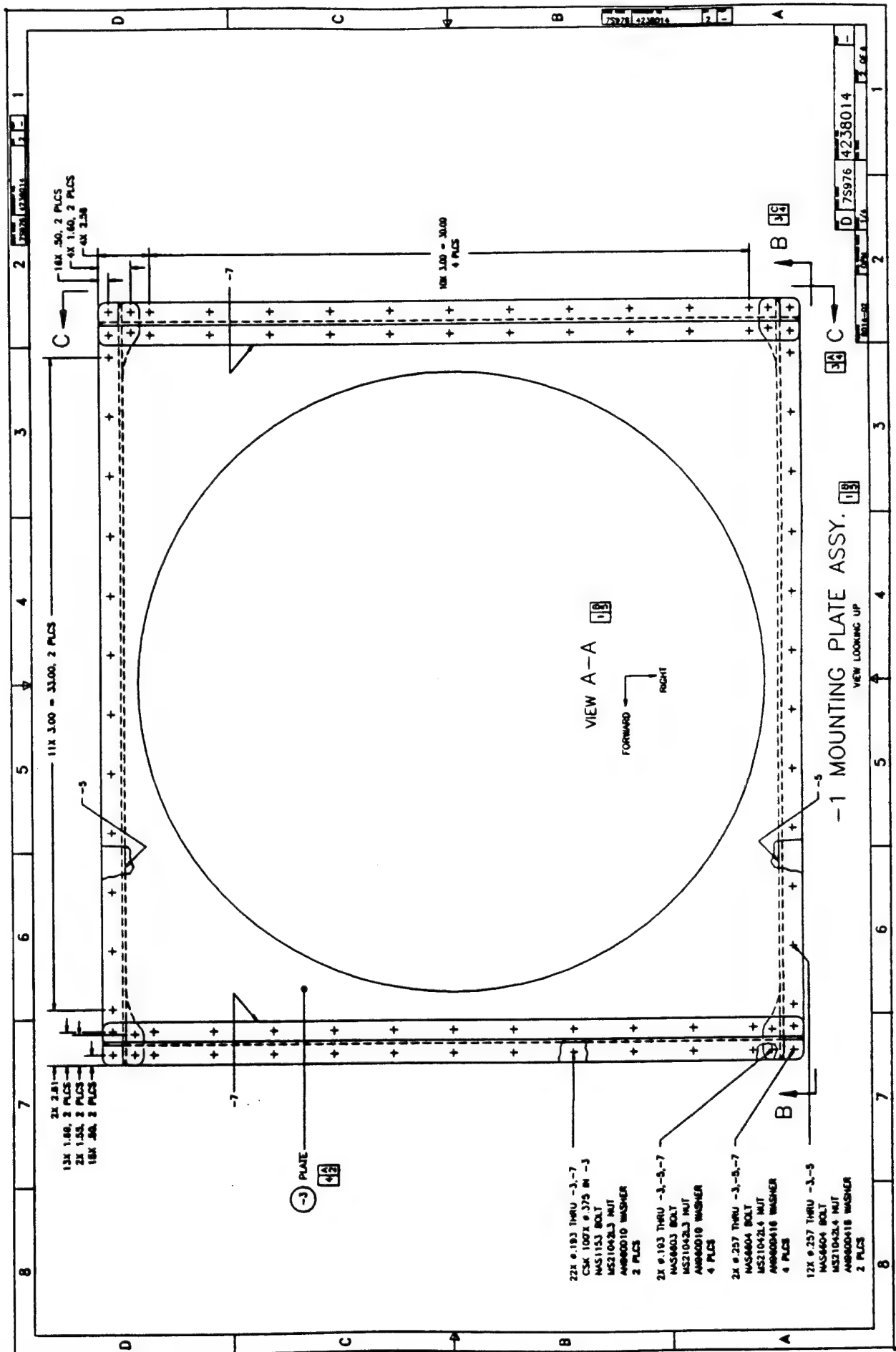
(3) Plate: use 1/4" stock

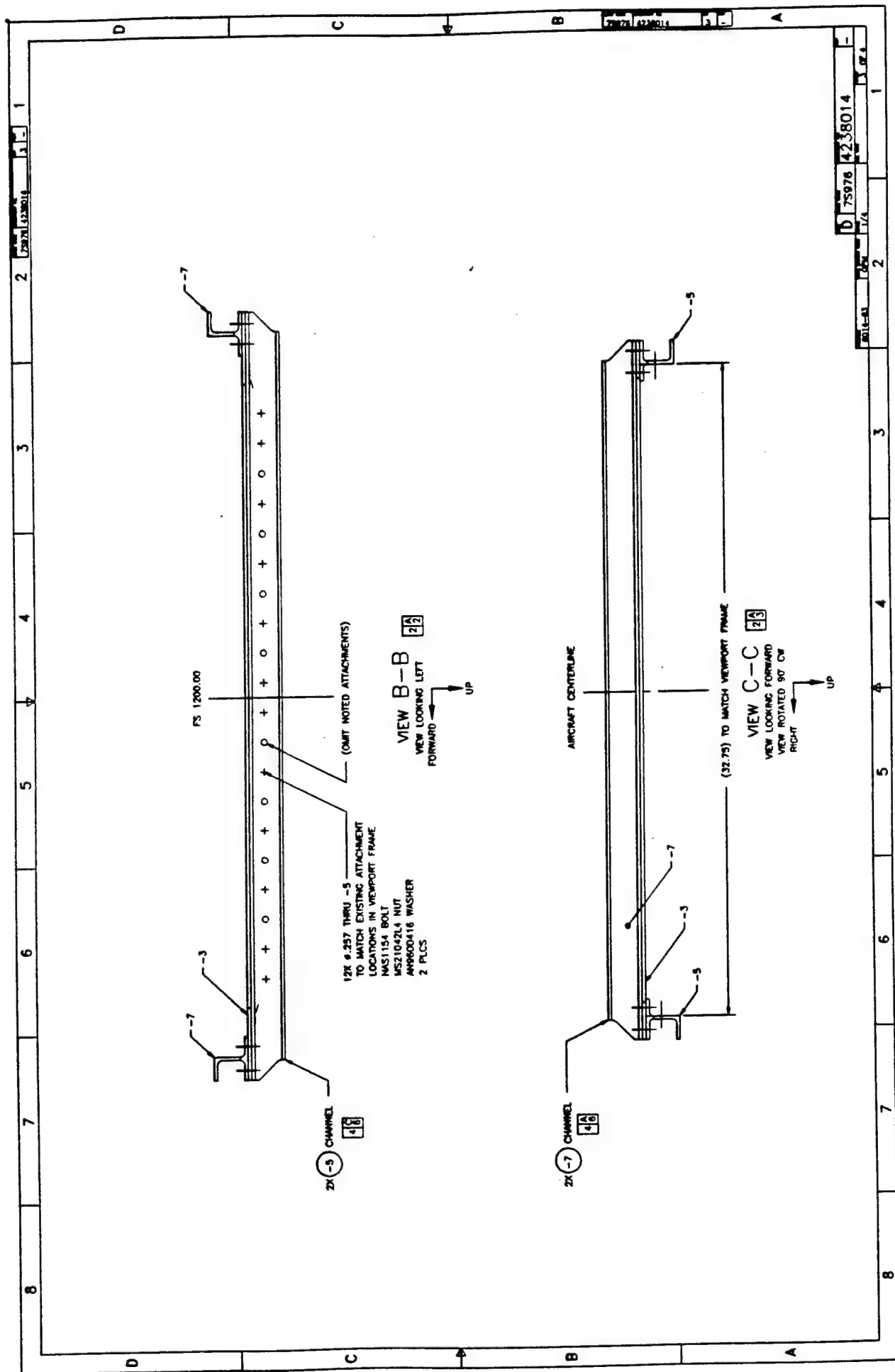
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND TOLERANCES ARE:		DRAWN	DATE	Georgia Institute of Technology	
XX 1/4 0.010		A.J. GOSWAMI	5/25/96	Hoisting Brackets	
XIII 1/4 0.010		APPROVED	DATE	Drawing #14	
XIV 1/4 0.010		DATE	DATE	Revision 1.0	
MATERIAL:		4 pcs req'd		SCALE	
6061 AL		of each		SHEET	



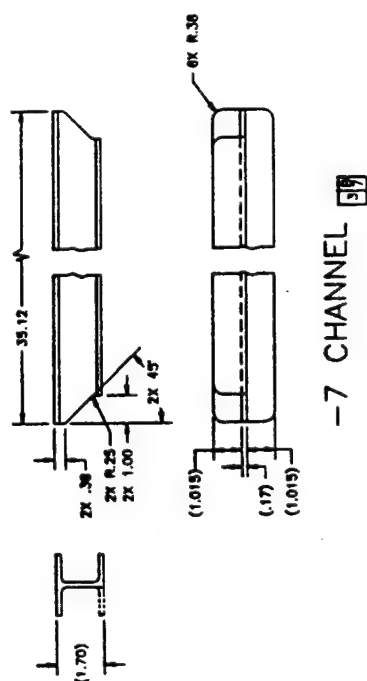
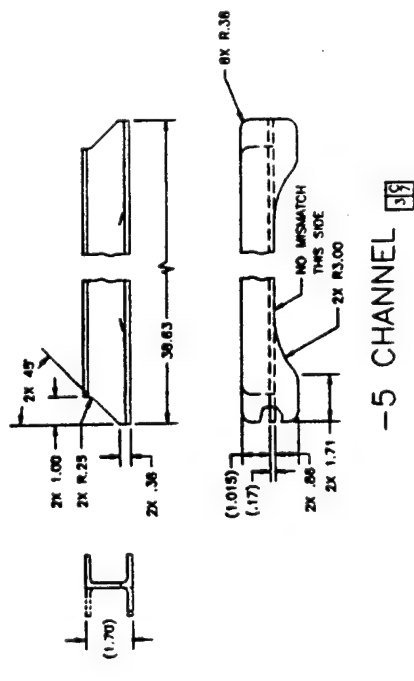
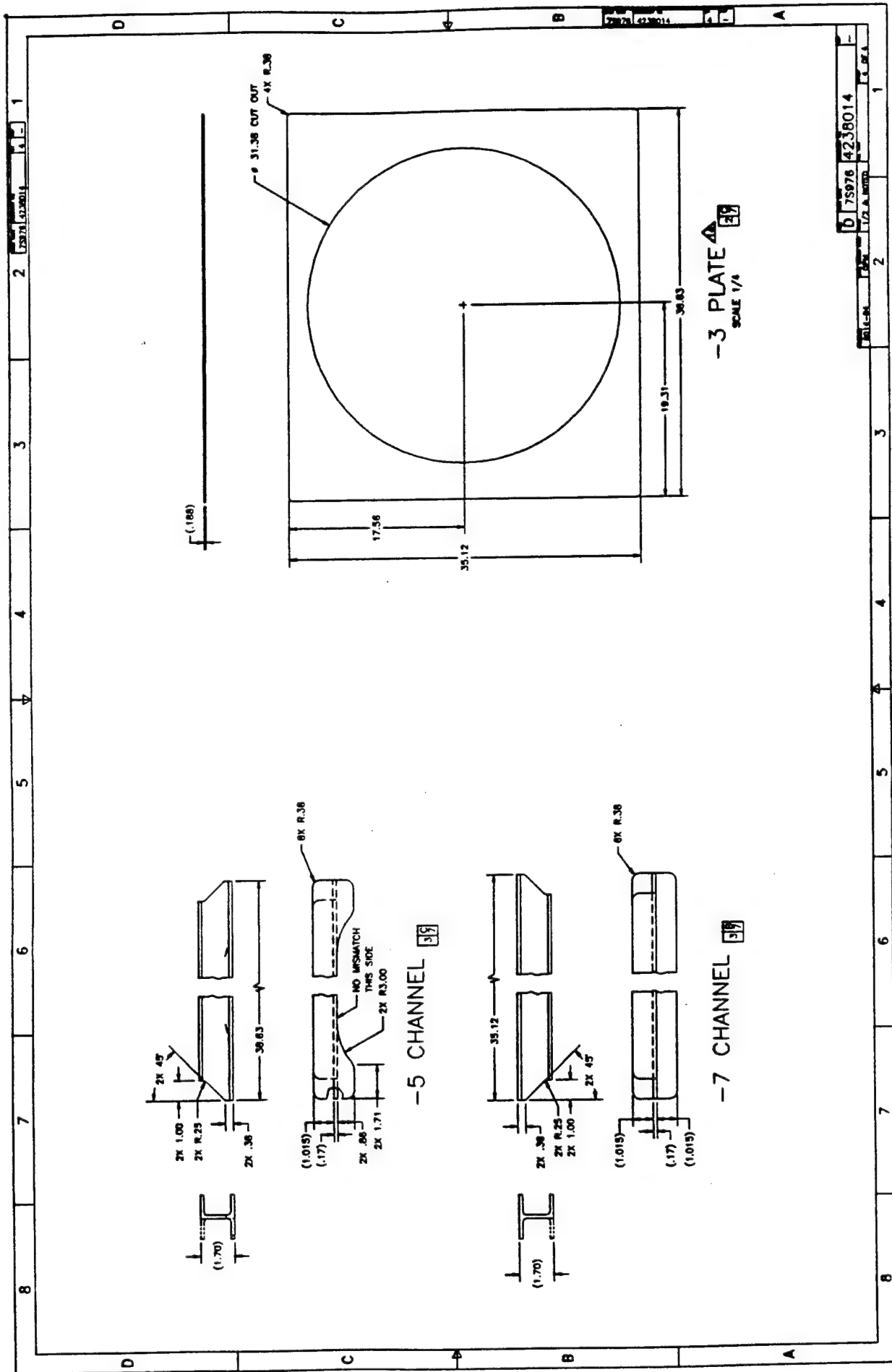


-1 DRUM ASSY/IN STL



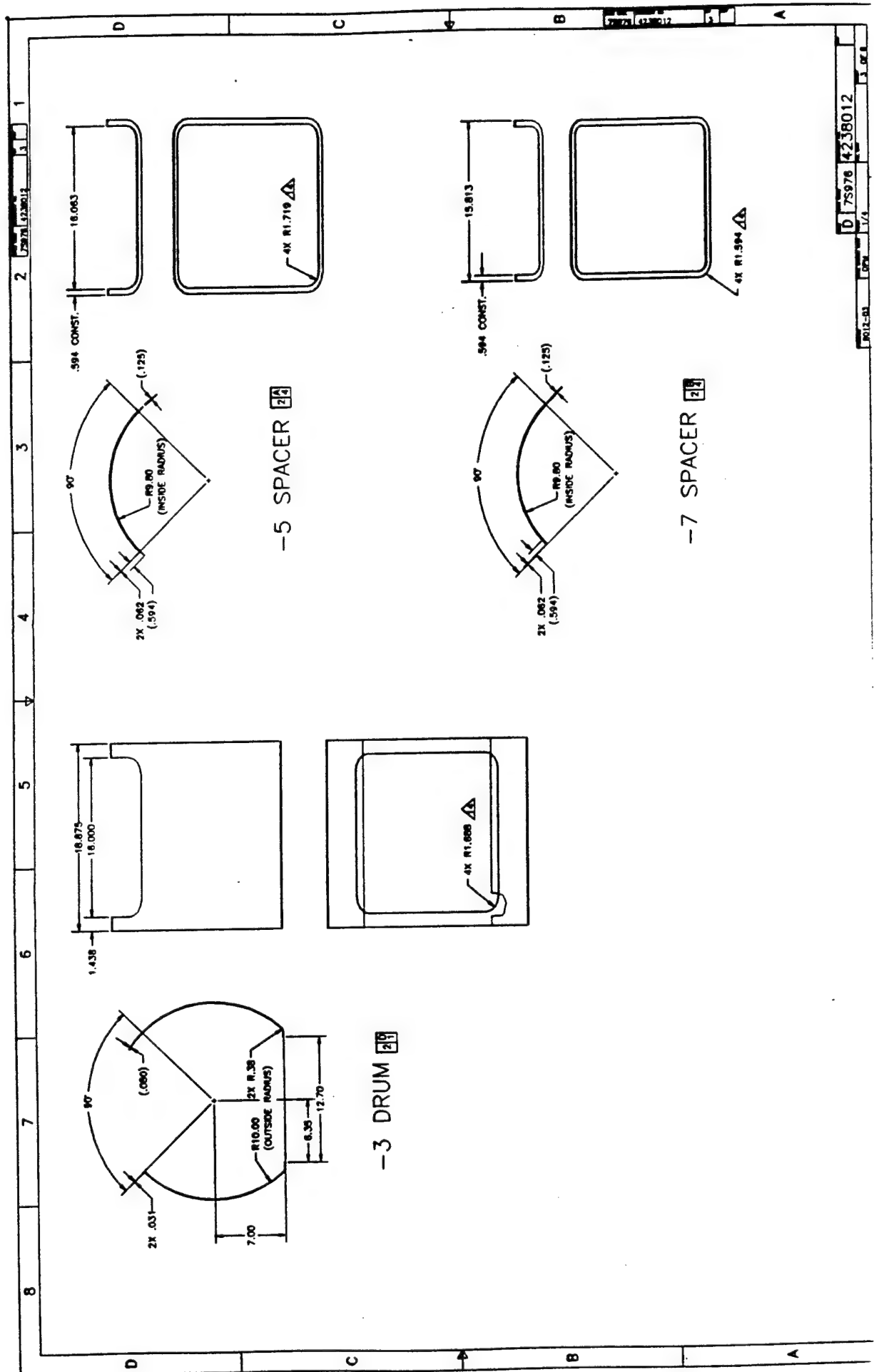




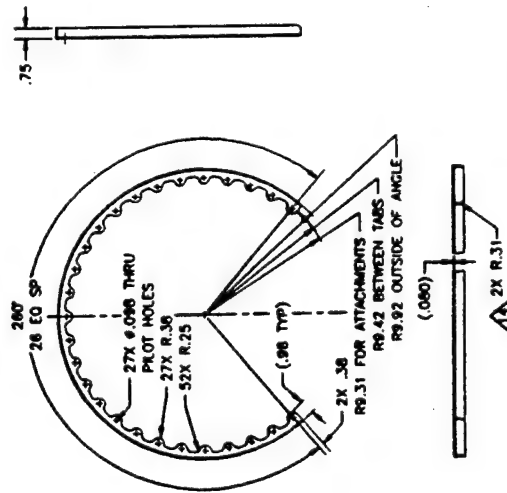




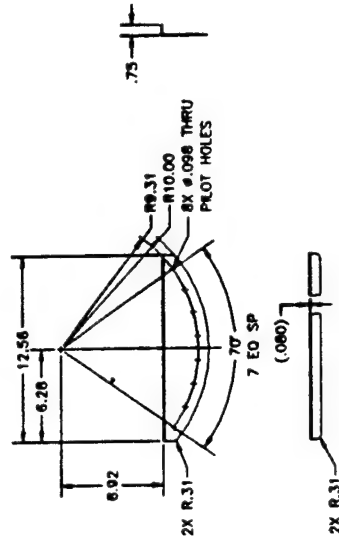




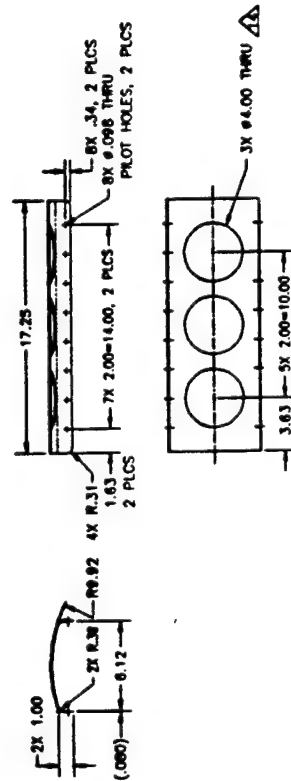




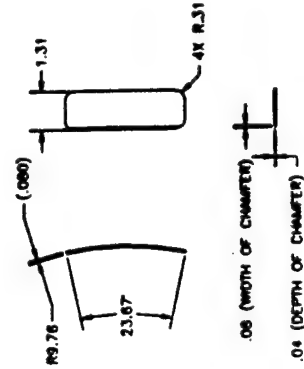
-13 RING ANGLE 29



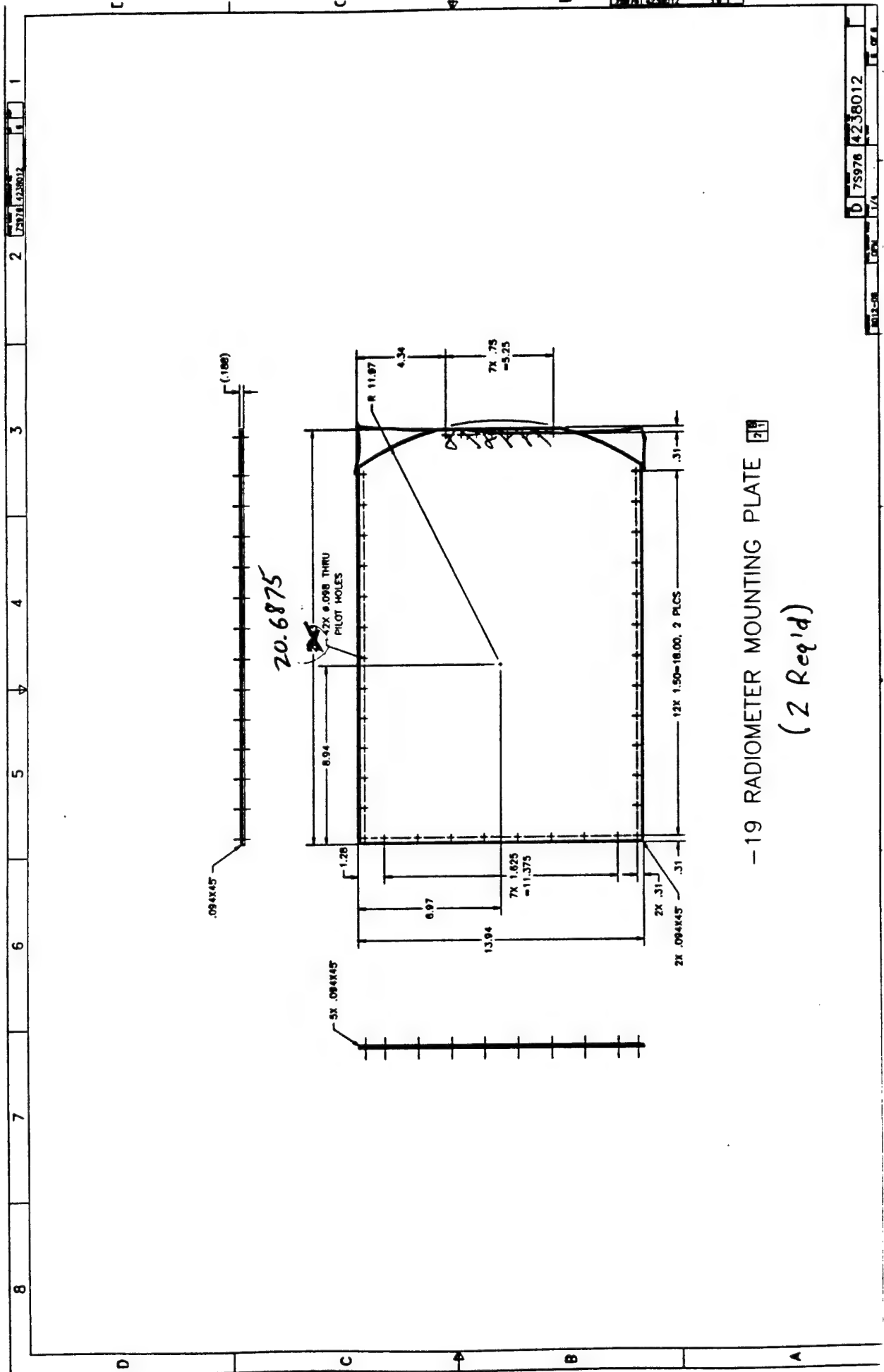
-15 CLIP 43



-17 STIFFENER 29

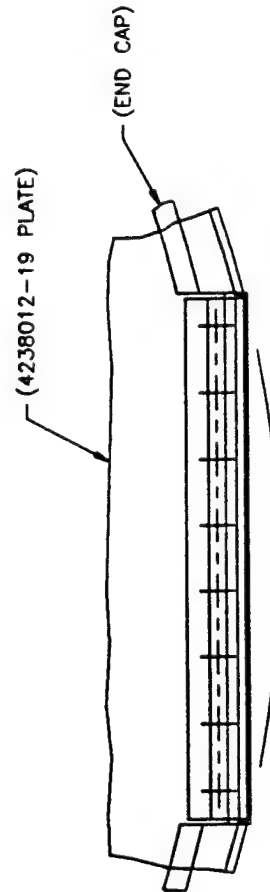
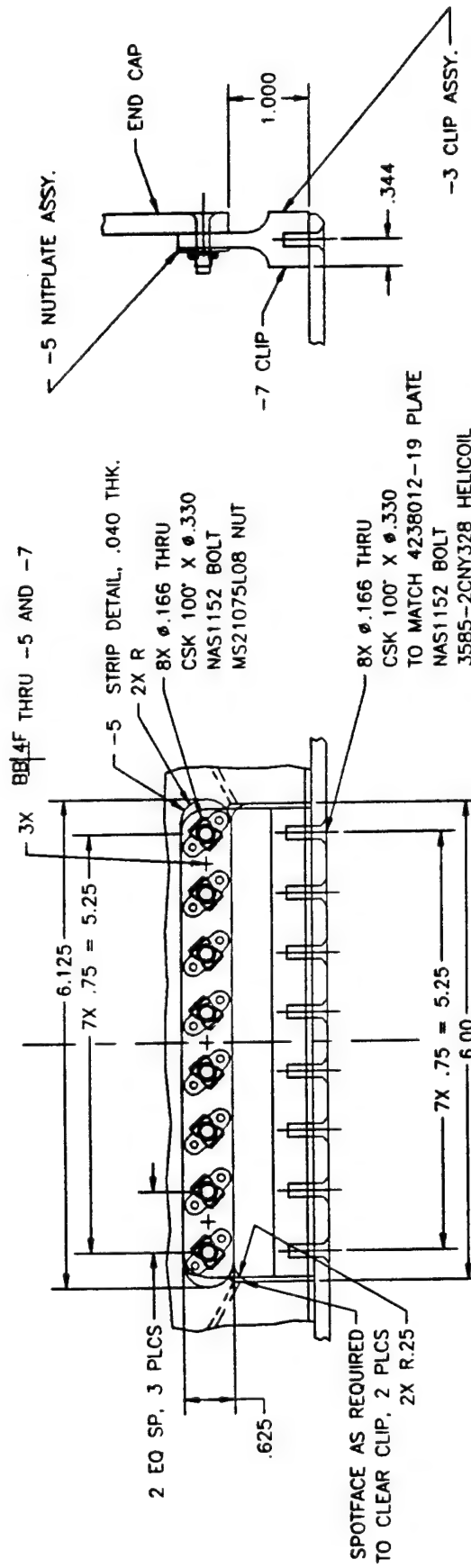


-23 SPLICE 29  
SCALE 1/2



-19 RADIOMETER MOUNTING PLATE 21  
 (2 Req'd)

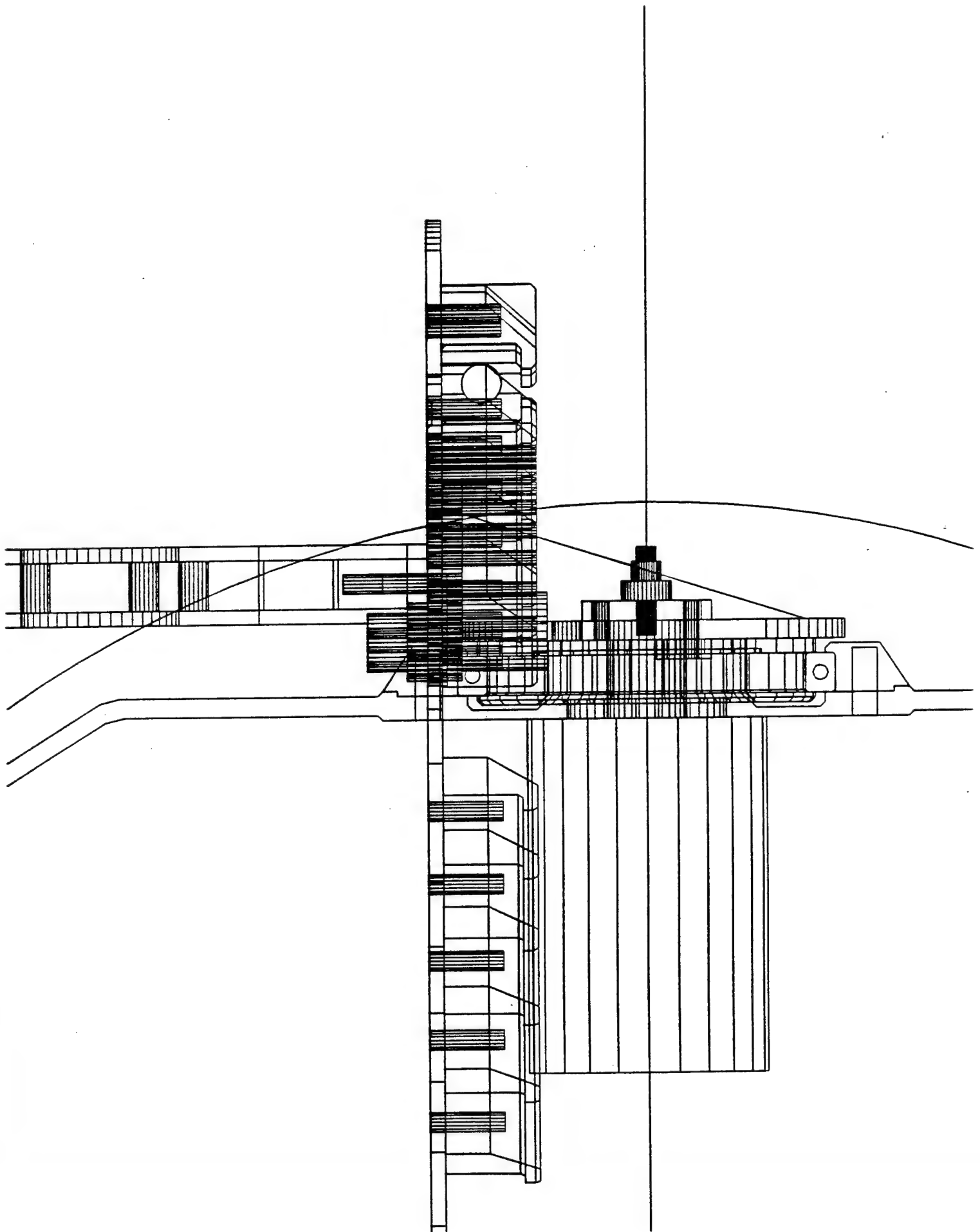
D C B A

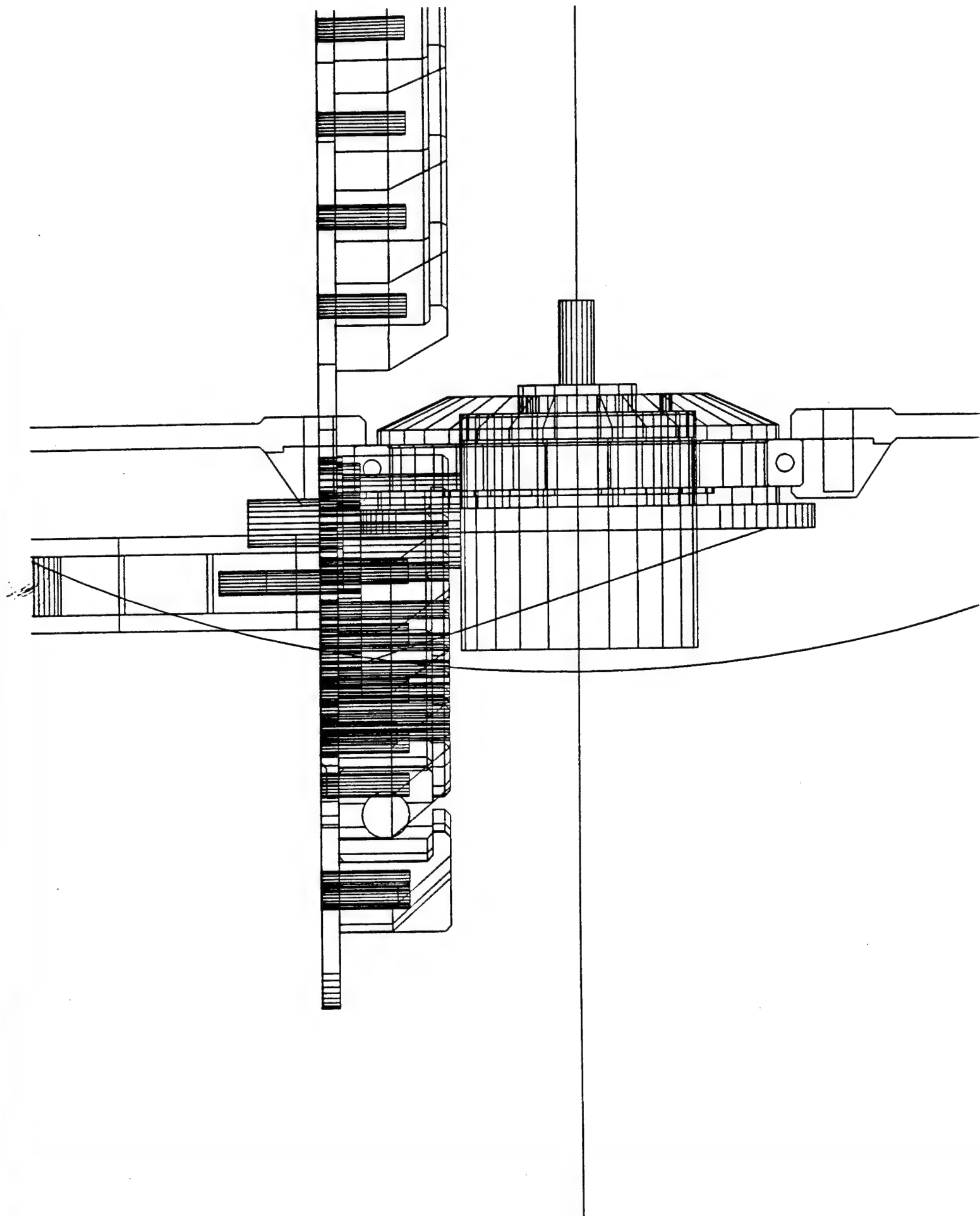


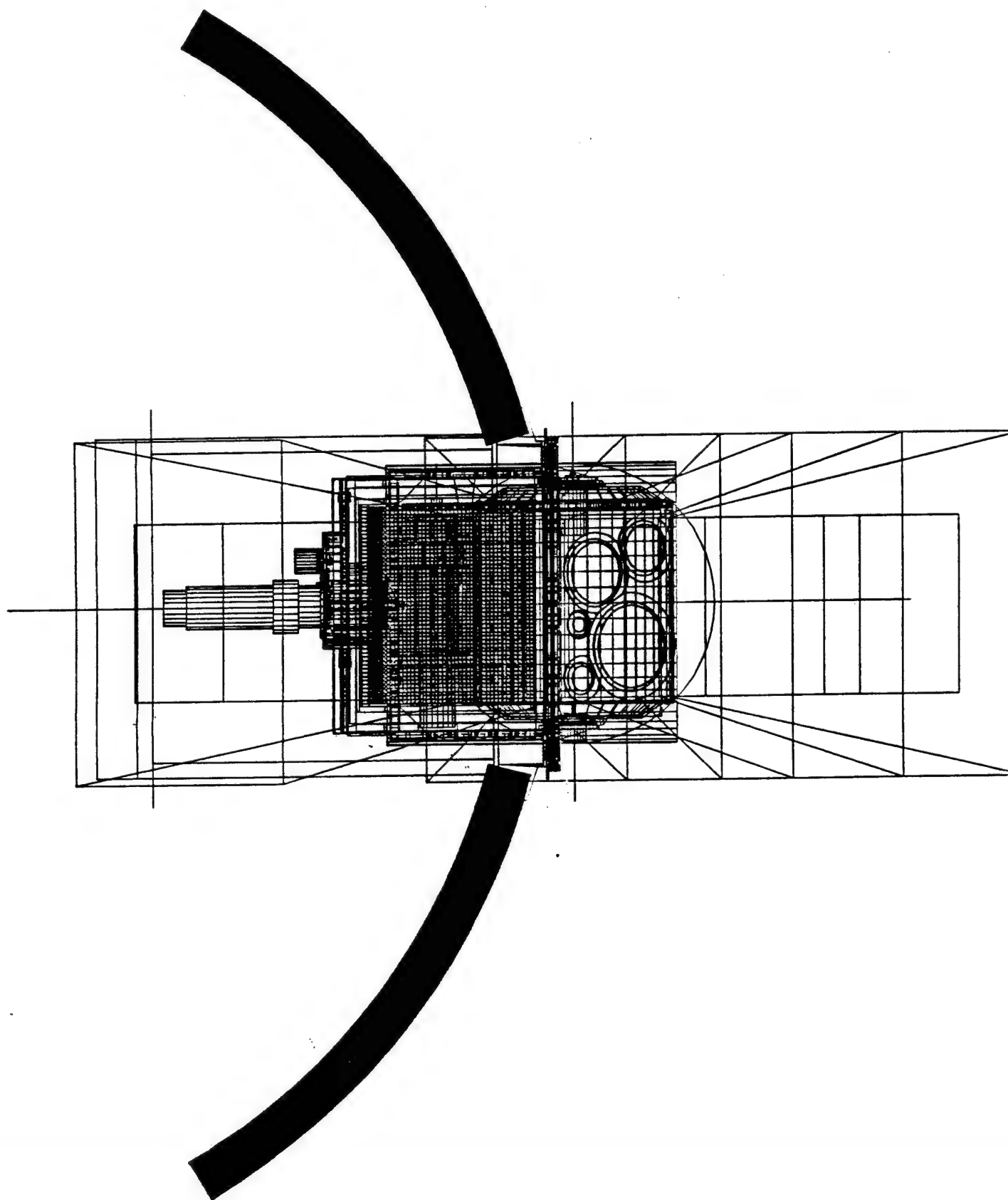
# -1 INSTALLATION

D C B A











## PSR Materials List

October 19, 1996  
(updated July 9, 1996)

A.J. Gasiewski  
(404) 894-2934 (O) (404) 894-4641 (F)  
ag14@prism.gatech.edu

Attached is a list of raw materials for major components of the PSR. The listed dimensions are exact, that is, they do not include excess material normally removed in the machining process. Additional lengths must be added to these prior to procurement so that the exact dimensions listed below can be obtained after machining.

All material must be requested with a foundry certification and laboratory report. Aluminum must be 2024 T351 for bar stock, 2024 T3 for plate, and 6061 for angle. Stainless steel must be 304 or higher grade.

Item	Description of Material
<b><u>Billets:</u></b>	
Driving-side endcap	20" diameter 2-1/2" thick 2024 Al disk
Idle-side endcap	20" diameter 1-7/8" thick 2024 Al disk
Azimuthal motor drum	13-1/8" diameter 2" thick 2024 Al disk
Yoke upper bearing drum	10" diameter 3-5/8" thick 2024 Al disk
Elevation brackets	10" x 6" x 3.5" 2024 Al block - to be cut diagonally to form two elevation bracket pieces.
Elevation motor mount M	7" x 6" x 2" thick 2024 Al block
Elevation motor mounts S	6" long 1-1/2x7x3/16 2024 Al blocks (two required)
<b><u>Plates:</u></b>	
Faceplates	14" x 21" x 3/16" thick 2024 Al plates (two required)
Horizontal mounting plate	35-5/8" x 25-1/2" x 1/4" thick 2024 Al plate
Outer flange plate	35.12 x 38.63 x 3/16" thick 2024 Al plate
Vertical support side plates	34-3/4" x 19-5/8" x 3/16" 2024 Al plates (two required)
Vertical support front/back plates	25-3/8" x 20-15/16" x 3/16" 2024 Al plates (two required)
Yoke side plates	15-1/2 x 8-1/4" x 3/16" thick 2024 Al plates (four required)
Yoke top plates	27" x 6" x 3/16" thick 2024 Al plates (two required)
Calibration load thermal plates V	17-9/16" x 21-1/4" x 1/4" thick 2024 Al plates (two required)
Calibration load thermal plates H	10-1/4" x 21-1/4" x 1/4" thick 2024 Al plates (two required)

Calibration load corner plates	10-1/2" x 17-9/16" x 1/2" thick 2024 Al plates (two rectangular plates required - four corner pieces will be cut from the two plates)
--------------------------------	---

Angles:

Vertical support structure V angles	17-13/16" long 1x1x3/16 6061 Al angles (eight required)
Vertical support structure F angles	7-9/16" long 1x1x3/16 6061 Al angles (four required)
Vertical support structure T angles	35-5/8" long 1x1x3/16 6061 Al angles (two required)
Vertical support structure B angles	20-1/2" long 1x1x3/16 6061 Al angles (two required)
Vertical support structure XL angles	23-1/2" long 1x1x3/16 6061 Al angles (two required)
Vertical support structure XU angles	25-1/2" long 1x1x3/16 6061 Al angles (two required)
Vertical support structure XB angles	23-1/2" long 1x1x3/16 6061 Al angles (two required)
Calibration load connector bracket	20-1/4" long 1x1x3/16 6061 Al angles (two required)

Bar stock:

Yoke side members	13-9/16" x 5/8" x 1" 2024 Al bars (four required)
Yoke top members	26-5/8" x 5/8" x 1" 2024 Al bars (two required)
Yoke elevation motor block S	4" x 5/8" x 2" 2024 Al block
Yoke elevation motor block S	4" x 5/8" x 1-1/2" 2024 Al block

Fiberglass:

Calibration load V mounting plates	18-13/16" x 25-1/2" x 3/8" fiberglass plates (two required)
Calibration load H mounting plates	11-1/2" x 23-1/2" x 3/8" fiberglass plates (two required)

Stainless steel:

Azimuthal shaft	7-3/16" x 2.75" OD x 1.125" ID SS shaft
Azimuthal shaft block	7-5/8" x 4" x 5/8" SS block

Misc components:

Azimuthal shaft bottom plate	4-3/4" x 6" x 1/4" thick 2024 Al plate
Yoke upper bearing outer seat	6-5/8" diameter x 5/8" thick 2024 Al disk
Yoke upper bearing inner seat U	4-3/8" diameter x 11/16" thick 2024 Al disk
Yoke upper bearing inner seat L	4-3/8" diameter x 5/16" thick 2024 Al disk
Elevation bearing outer seats	6-5/8" diameter x 5/8" thick 2024 Al disks (two required)
Elevation bearing inner seats	4-3/8" diameter x 1" thick 2024 Al disks (two required)
Main ring bearing inner seats	4-1/2" x 18" x 1-3/16" 2024 Al blocks (two required)
Main ring bearing outer seats	1-3/4" x 6" x 1-3/16" 2024 Al blocks (twelve required)
Yoke lower plugs	2-1/4" x 8" x 5/8" 2024 Al blocks (two required)
Yoke corner plugs	2" x 2" x 4" 2024 Al blocks (two required)

Miscellaneous:

Azimuthal shaft lower keyways	5/8" x 1/4" x 1/4" steel (two required)
Azimuthal shaft motor keyway	1-3/8" x 1/4" x 1/4" steel (one required)

## PSR-2 Fastener Summary

A.J. Gasiewski  
October 19, 1995  
(updated February 3, 1996)

### Fastener Summary by Application

Fastening task:	Qty	Part number <sup>1,2</sup>	Description
Outer flange plate bearing seats			
Beneath window frame <sup>3</sup>	30	NAS 1153-22	1.651" #10-32 torq-set flat head bolts
Clear of window frame <sup>4</sup>	30	NAS 1143-22	1.651" #10-32 torq-set pan head bolts
	60	MS21042L3	#10-32 lock nuts
	60	AN960D10	#10 washers
Inner flange plate bearing seats <sup>4</sup>	38	NAS 1143-22	1.651" #10-32 torq-set pan head bolts
	38	MS21042L3	#10-32 lock nuts
	38	AN960D10	#10 washers
Structural yoke assembly:			
Yoke plates (top, sides)	58	NAS 6604-G-14	1.300" 1/4-28 hex head bolts
Az shaft bottom plate	10	NAS 1351-4-16P	1" 1/4-28 cap screws
Corner plugs (through)	10	NAS 6604-G-14	1.300" 1/4-28 hex head bolts
Motor mounts to yoke top	15	NAS 6604-G-18	1.550" 1/4-28 hex head bolts
Azimuthal shaft block side	4	NAS 1351-4-28P	1-3/4" 1/4-28 cap screws
Corner plugs (blind)	10	NAS 603-10P	0.62" #10-32 pan head bolts
Yoke top plate corners (blind)	4	NAS 603-10P	0.62" #10-32 pan head bolts
Motor mount gussetts to yoke	8	NAS 603-12P	0.75" #10-32 pan head bolts
Motor mount gussetts-mount	12	NAS 603-12P	0.75" #10-32 pan head bolts

<sup>1</sup> All high-strength aircraft hardware - 160 kpsi tensile strength - NAS or MS series.

<sup>2</sup> All indicated bolt lengths include the grip plus thread length, but do not include the head length. An exception are flat head bolts for which the indicated length specifies the *entire* length. Flat head bolts use 100° head angle.

<sup>3</sup> May also use NAS 517-3-22 (1.781" #10-32 standard phillips flat head bolts).

<sup>4</sup> May also use NAS 623-3-22 (1.651" #10-32 standard phillips pan head bolts).

Corner gussetts	24	NAS 603-12P	0.75" #10-32 pan head bolts
Az. shaft to az. bottom plate	4	NAS 1351-4-16P	1" 1/4-28 cap screws
Upper bearing race stack	4	NAS 1351-4-32P	2" 1/4-28 cap screws
Upper bearing race to az shaft	2	NAS 1351-3-16P	1" #10-32 cap screws
Electrical connector brackets	4	NAS 603-12P	0.75" #10-32 pan head bolts
	12	MS21042L3	#10-32 lock nuts
	83	MS21042L4	1/4-28 lock nuts
	78	AN960D10	#10 washers
	194	AN960D416	1/4" washers
Elevation bracket attachment:			
Yoke bottom plugs	8	NAS 1351-4-20P	1-1/4" 1/4-28 cap screws
Inner flange plates	12	NAS 1351-4-12P	3/4" 1/4-28 cap screws
	20	AN960416	1/4" steel washers
	12	MS21075L4	1/4-28 capture nuts
	24	MS20426DD3-6	3/8" x 3/32" dia flat head rivets
Azimuthal drum attachment:			
Through one drum flange each	14	NAS 623-4-8	0.816" 1/4-28 pan head bolts
Through both drum flanges	2	NAS 623-4-12	1.066" 1/4-28 pan head bolts
	2	MS21042L4	1/4-28 lock nuts
	14	MS21075L4	1/4-28 capture nuts
	28	MS20426DD3-7	7/16" x 3/32" dia flat head rivets
	18	AN960D416	1/4" washers
Drive motor attachment:			
Elevation motor	8	NAS 517-4-6	0.844" 1/4-28 flat head bolts
Azimuthal motor	8	NAS 517-4-6	0.844" 1/4-28 flat head bolts
Secondary elevation mount	2	NAS 1351-3-28P	1-3/4" #10-32 cap screws
Tertiary elevation mount	1	NAS 1351-08-12P	3/4" #8-32 cap screws
	1	MS21042L08	#8-32 lock nuts
	2	MS21042L3	#10-32 lock nuts
	16	MS21042L4	1/4-28 lock nuts
	1	AN960D8	#8 washers
	2	AN960D10	#10 washers
	16	AN960416	1/4" steel washers
Bearing seat attachment:			
Drive endcap inner seats	6	NAS 517-4-14	1.343" 1/4-28 flat head bolts
	6	AN960D416	1/4" washers
	6	MS21042L4	1/4-28 lock nuts



Drive endcap outer seats	6	NAS 517-4-14	1.343" 1/4-28 flat head bolts
	6	MS21042L4	1/4-28 lock nuts
	6	AN960D416	1/4" washers
Idle endcap inner seats	6	NAS 1351-4-20P	1-1/4" 1/4-28 cap screws
	6	AN960D416	1/4" washers
Idle endcap outer seats	6	NAS 517-4-14	1.343" 1/4-28 flat head bolts
	6	MS21042L4	1/4-28 lock nuts
	6	AN960D416	1/4" washers
Azimuthal shaft outer seat	6	NAS 1351-4-12P	3/4" 1/4-28 cap screws
	6	AN960D416	1/4" washers
Drum:			
Idle side endcap attachment <sup>5</sup>	28	NAS 623-3-6	0.651" #10-32 pan head bolts
	28	MS21075L08	#10-32 lock nuts
	56	AN960D10	#10 washers
Drive side endcap attachment <sup>6</sup>	35	NAS 623-3-18	1.401" #10-32 pan head bolts
	35	MS21042L3	#10-32 lock nuts
	35	AN960D10L	#10 thin washers
	35	AN960D10	#10 washers
Faceplate attachment	34	NAS 1102-08-8	0.500" #8-32 flat head bolts
	34	MS21075L08	#8-32 capture nuts
	68	MS20426DD3-4	1/4" x 3/32" dia flat head rivets
	7	NAS 1102-08-8	0.500" #8-32 flat head bolts
	6	NAS 514P632-16P	0.500" #6-32 flat head bolts
Clip attachment	7	NAS 1102-3-12	0.750" #10-32 flat head bolts
	7	MS21042L3	#10-32 lock nuts
	7	AN960D10	#10 washers
Lens/feedhorns to faceplate	32	NAS 1102-3-18	1.125" #10-32 flat head bolts
	32	MS21042L3	#10-32 lock nuts
	64	AN960D10	#10 washers
Scanhead access port cover	18	NAS 1152-3	0.464" #8-32 torq-set flat head screws

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<sup>5</sup> May also use NAS 623-3-6 (0.651" #10-32 standard phillips pan head bolts).

<sup>6</sup> May also use NAS 623-3-18 (1.401" #10-32 standard phillips pan head bolts).

Calibration loads:

Fiberglass-to-front/back plates <sup>7</sup>	32	NAS 517-4-6	0.844" 1/4-28 flat head bolts
Fiberglass-to-horz plate	24	NAS 6604-G-8	0.925" 1/4-28 hex head bolts
	48	AN970-4	1/4" fender washers
	48	AN960D416L	1/4" thin washers
	48	MS21042L4	1/4-28 lock nuts
Load-to-fiberglass (front/back)	24	NAS 6604-G-16	1.425" 1/4-28 hex head bolts
Load-to-fiberglass (top)	20	NAS 6604-G-16	1.425" 1/4-28 hex head bolts
	44	MS21075L4	1/4-28 capture nuts
	88	MS20426DD3-7	7/16" x 3/32" dia flat head rivets
	44	AN970-4	1/4" fender washers
Gussett plate attachment	52	NAS 603-12P	0.75" #10-32 pan head bolts
	52	AN960D10	#10 washers
Corner bracket attachment	32	NAS 603-12P	0.75" #10-32 pan head bolts
	32	MS21042L3	#10-32 lock nuts
	32	AN960D10	#10 washers

Vertical support structure:

Horz plate - sides	28	NAS 6604-G-6	0.800" 1/4-28 hex head bolts
	28	MS21042L4	1/4-28 lock nuts
	56	AN960D416L	1/4" thin washers
Horz plate - front/back	24	NAS 1154-7	0.754" 1/4-28 torq-set flat head bolts
	24	MS21042L4	1/4-28 lock nuts
	48	AN960D416L	1/4" thin washers
Side plates	152	NAS 6604-G-6	0.800" 1/4-28 hex head bolts
	152	MS21042L4	1/4-28 lock nuts
	304	AN960D416L	1/4" thin washers
Front/back plate	68	NAS 1154-7	0.754" 1/4-28 torq-set flat head bolts
Front/back plate/fiberglass	36	NAS 517-4-10	1.093" 1/4-28 flat head bolts
	104	MS21042L4	1/4-28 lock nuts
	208	AN960D416L	1/4" thin washers
Outer flange plate attachment	40	NAS 6604-G-6	0.800" 1/4-28 hex head bolts
	40	MS21042L4	1/4-28 lock nuts
	80	AN960D416L	1/4" thin washers

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<sup>7</sup> Attachment of the fiberglass plates to the front and back plates requires countersinking and spotfacing the flat washer/nut assembly into the fiberglass 1/8" deep for clearance when installing loads.

Electrical connectors:

Size 28 (azimuth slipring)	4	NAS 601-12P	0.75" #6-32 pan head screws
	4	MS21042L06	#6-32 nuts
	8	AN960D6	#6 washers
Sizes 18, 20, & 22 (11 total)	44	NAS 600-12P	0.75" #4-40 pan head screws
	44	MS21042L04	#4-40 nuts
	88	AN960D4	#4 washers

Miscellaneous (including internal to scanhead):

General #4-40 attachment	36	NAS 514P440-16P	1" #4-40 flat head screws
	36	NAS 600-16P	1" #4-40 pan head screws
	72	MS21042L04	#4-40 nuts
	144	AN960D4L	#4 thin washers
General #6-32 attachment	24	NAS 514P632-16P	1" #6-32 flat head screws
	24	NAS 601-16P	1" #6-32 pan head screws
	24	NAS 1351-06-16P	1" #6-32 cap screws
	72	MS21042L06	#6-32 nuts
General #8-32 attachment	144	AN960D6L	#6 thin washers
	24	NAS 1102-08-16	1" #8-32 flat head bolts
	24	NAS 602-16P	1" #8-32 pan head bolts
	24	NAS 1351-08-16P	1" #8-32 cap screws
General #10-32 attachment	72	MS21042L08	#8-32 lock nuts
	144	AN960D8L	#8 thin washers
	24	NAS 1102-3-20	1-1/4" #10-32 flat head bolts
	24	NAS 603-20P	1-1/4" #10-32 pan head bolts
General 1/4-28 attachment	24	NAS 1351-3-16P	1" #10-32 cap screws
	72	MS21042L3	#10-32 lock nuts
	144	AN960D10L	#10 thin washers
	24	NAS 517-4-16	1.468" 1/4-28 flat head bolts
	24	NAS 604-24P	1-1/2" 1/4-28 pan head bolts
	48	MS21042L4	1/4-28 lock nuts
	96	AN960D416L	1/4" thin washers